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THE NAVAJO COUNTRY

A GEOGRAPHIC AND HYDROGRAPHIC RECONNAISSANCE OF PARTS OF ARIZONA, NEW MEXICO, AND UTAH

BY

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INTRODUCTION.

A PERSONAL WORD.

To my mind the period of direct contact with nature is the true "heroic age" of human history, an age in which heroic accomplishment and heroic endurance are parts of the daily routine. The activities of people on this stage of progress deserve a place among the cherished traditions of the human race. I believe also that the sanest missionary effort includes an endeavor to assist the uncivilized man in his adjustment to natural laws. With these ideas in mind the opportunity to conduct exploratory work in the Navajo country appealed to me with peculiar force. Within this little-known region are the remnants of an almost extinct race whose long occupation of the country is recorded in ruined dwellings and abandoned fields. This country is also the home of the vigorous and promising Navajos—a tribe in remarkably close adjustment to their physical surroundings. To improve the condition of this long-neglected but capable race, to render their life more intelligently wholesome by applying scientific knowledge, gives pleasure in no degree less than that obtained by the study of the interesting geologic problems which this country affords.

HISTORY AND SCOPE OF INVESTIGATION.

The work on which the present report is based was begun in 1909 at the request of the United States Office of Indian Affairs. In May of that year, in company with M. R. Campbell and W. C. Mendenhall, of the United States Geological Survey, and under the intelligent guidance of H. F. Robinson, irrigation engineer of the Indian Office, I made a rapid trip to points in the southern portion of the Navajo and Hopi reservations, including Leupp, Tuba, the Hopi villages, Keams Canyon, Ganado, Chinle, and Fort Defiance, Ariz. Field work was continued until late in September.

The working season of 1910 was reduced to three weeks on account of illness contracted in the field. During the summer of 1911 work was confined to the southern and eastern portions of the reservations in Arizona and New Mexico. The particular problem for 1913 was an examination of the region along Little Colorado River, but studies were made also in the area adjoining Navajo Mountain and along the Santa Fe Railway. A detailed study of Carrizo Mountain was made during this year by my assistant, W. B. Emery. From time to time reports have been submitted to the Indian Office on various phases of the work, including irrigation projects, well construction, and sites for schools and for hospitals. These reports are of such a nature as not to find place in printed public documents and are therefore not included in the present paper.

With the time at our disposal the field work was necessarily reconnaissance because of the large area to be covered, the great diversity of topographic and geologic features, and the difficulties presented by scarcity of water and of forage. Moreover the literature covering this area relates chiefly to archeologic details of a few accessible places, and oral information obtained from the few men who know the region through personal experience was so fragmentary and contradictory that a large part of our work was essentially exploratory.

The future of the Navajo country depends fundamentally on the solution of one problem—the water supply—and therefore both reconnaissance and detailed work were designed to procure data bearing on this problem. The geography of the region was also studied, with a view to preparing a description of this little-known part of the United States—an account designed to facilitate the work of those who are to supplement our preliminary examination by detailed studies.

ACKNOWLEDGMENTS.

In a region which has previously been unexplored and in which the Indians are none too cordial the successful prosecution of field work is to a large degree dependent on the assistance rendered by Government authorities and the few local men who are acquainted with the country and its uncivilized inhabitants. In this connection it is a pleasure to acknowledge the hearty cooperation of officials of the Indian Office, both in Washington and in the field. In particular the friendship and assistance of Peter Paquette, superintendent of the Navajo Reservation, and of H. F. Robinson, superintendent of irrigation, has substantially increased the value of our studies. To the fact that Mr. Paquette, Mr. Hubbell, one of the Indian traders, and Father Weber, a Franciscan priest, believed in our work and explained our mission to the Navajos is due the friendly attitude of the Indians, which was very evident, especially after the first season. The loyalty and efficiency of my scientific assistants, J. E. Pogue,

W. B. Emery, and especially K. C. Heald, all of whom unflinchingly endured the hardships and uncertainties of desert travel over little-known trails, is recorded with peculiar gratitude. The devotion of our Navajo assistants, Grover Cleveland, Eugene Sosi, Denet Bahe, and John Sheen, added much to our comfort and at times saved us from disagreeable experiences if not from disaster. The Indian traders, particularly the Hubbells, Wetherill & Colville, Mr. Preston, and the Mannings, greatly facilitated our work by helpful advice and by direct financial assistance. The store of linguistic knowledge accumulated by the Franciscan fathers was freely placed at our disposal, as were also the results of their studies of the conditions and needs of the Navajos. Acknowledgment is thankfully made of the assistance given by the fathers in regard to the spelling and interpretation of Navajo place names used in this paper.

SUGGESTIONS TO TRAVELERS.

The following information, acquired by personal experience, may be found helpful for those who desire to leave the main traveled roads in this region.

The Navajo is vigorous, intelligent, and capable of hard work if it is not too continuous. He will render assistance for pay, frequently for friendship, and is loyal and cheerful when fairly treated. He is, however, independent, and will desert with scant ceremony when unjustly treated. He will help himself to interesting trinkets and to food but may be trusted with valuable things and with important missions. He is a past master at driving a bargain. He is an expert horseman but knows little of harness, wagons, and pack outfits. His knowledge of distances and of directions is of such nature as to be of little use to a white man. It is essential to success that the Navajo should understand and approve of you and of your mission, and therefore frankness should characterize all dealings with him. A Navajo, preferably a school boy recommended by a superintendent, should be a member of each party, not only to serve as guide and interpreter but to obtain advance information regarding water and forage and to establish friendly relations with those Indians who have slight acquaintance with the whites.

The Hopi is indifferent toward you and your mission. He offers no aid, and yet rarely refuses to lend assistance when called upon. He looks after his own affairs with intelligence and devotion but takes little interest in yours. His chief desire is to be let alone. The Piute, in my opinion, is less trustworthy and less skillful than his Navajo and Hopi neighbors.

The prevalent Indian diseases are tuberculosis and trachoma, a fact which should be kept in mind when hospitality is extended or accepted.

The Indian schools of Fort Defiance, Keams Canyon, Crown Point, Leupp, Tuba, and Shiprock are connected with the railroads by roads which, judged by pioneer standards, may be classed as good. The better-known features of interest, Canyon de Chelly and the Hopi villages, are also accessible by wagon. "Roads," in the local sense—that is, routes over which a staunchly built, lightly loaded wagon drawn by two, four, or more horses may be taken by skillful drivers—may be found here and there, especially in the southern and eastern parts of the reservations. The land of the Navajos is, however, preeminently a "horseback country," and a pack train is the only type of outfit which offers freedom of movement. Quicksand is to be expected in all stream channels and in the beds of "dry lakes," and crossings should be tested before wagons or pack trains are intrusted to them. Owing to sudden rises of water, streams and dry washes should be crossed at the earliest favorable opportunity, and camp should never be pitched on the floor of even the most innocent looking dry stream bed or adobe flat.

Suitable outfits and guides for scientific exploration and tourist travel may be obtained from Wetherill & Colville, at Tyende, and under certain circumstances from J. L. Hubbell, at Ganado. Unless, however, arrangements have been previously made, equipment should be procured at Gallup, Holbrook, Winslow, Flagstaff, Farmington, or other points on the railway.

The location of camps is necessarily controlled by the distribution of water, and the traveler should have reliable information regarding water holes and springs for the particular month during which he proposes to make his expedition. Grain for horses should be provided, as very few places afford the essentials of camp—water, wood, and forage—and barren zones surround most of the water supplies. Not all stores carry grain, and inquiries as to the amount available should be made beforehand. Fuel is lacking at many camp sites or is limited to yucca, grass, and annuals. Under such circumstances the abandoned "hogans" appear tempting; but some of these deserted huts have housed dying persons, and are therefore taboo, and their use may lead to trouble. The traveler should never leave camp without a supply of water and should keep in mind the deceptive character of mirages. The danger from lightning may be minimized by avoiding the shelter of trees during the thunderstorms that almost invariably accompany summer rains.

Reliable information may be obtained from the officials at the various Government schools and from those traders and missionaries who have been long in contact with the Navajos.

PART I. GEOGRAPHY.

LOCATION AND EXTENT OF RESERVATIONS.

The Navajo and Hopi Indian reservations, though officially distinct, are treated as a unit in this report. They lie approximately between parallels 35° 10′ and 37° 17′ and meridians 108° 15′ and 111° 45′. (See Pl. I, in pocket.) The lands reserved for the Indians embrace parts of Coconino, Navajo, and Apache counties, in Arizona; parts of McKinley and San Juan counties, in New Mexico; and the southern part of San Juan County, Utah. For purposes of administration the Indian lands are divided into reservations—the Pueblo Bonito, San Juan, Navajo, Navajo Extension, Western Navajo, and Hopi—each in charge of a superintendent or agent. The area of the reservations is 14,333,354 acres, or about 22,400 square miles, an area larger than Connecticut, Rhode Island, Massachusetts, and New Hampshire combined. The distance across the reservations in an east-west line from Crown Point, N. Mex., to Black Falls, on the Little Colorado in Arizona, is about 190 miles, and from Bluff, Utah, southward to Chambers, on the Santa Fe Railway, is approximately 140 miles. Administrative centers are reached from the railway as follows: Pueblo Bonito (Crown Point), from Thoreau, N. Mex., 29 miles; Fort Defiance, from Gallup, N. Mex., 35 miles; Keams Canyon, from Gallup, N. Mex., 107 miles; or from Holbrook, Ariz., 65 miles; Leupp, from Canyon Diablo, Ariz., 12 miles; Tuba, from Flagstaff, Ariz., 90 miles; Shiprock, from Farmington, N. Mex., 35 miles. The Chinle School is 95 miles from the railway, and the most remote point to which mail is regularly carried is Tyende, 165 miles from the nearest railway station. The northwestern part of the Western Navajo Reservation, beyond the farthest outpost, is singularly inaccessible.

The roads leading from New Mexico and Arizona settlements to the chief points within the reservations, though rough, are feasible for wagons. Roads have also been established along selected routes to reach newly established schools and trading posts and important centers of Indian population. The larger part of the reservations is, however, accessible only by trails, and in the rougher areas no recognized routes of travel are to be found. Saddle horse and pack train capable of making long day's marches are necessary for the prosecution of geographic or geologic field work.

NOTE ON THE MAP.

The area described in this report includes not only the Navajo and Hopi reservations as officially limited but also four adjacent areas: One extending eastward in New Mexico from the reservation line to the 108th meridian; one bordering the Santa Fe Railway; one along the lower part of San Juan River; and a small area near the mouth of the Little Colorado. (See fig. 1.) These strips, though

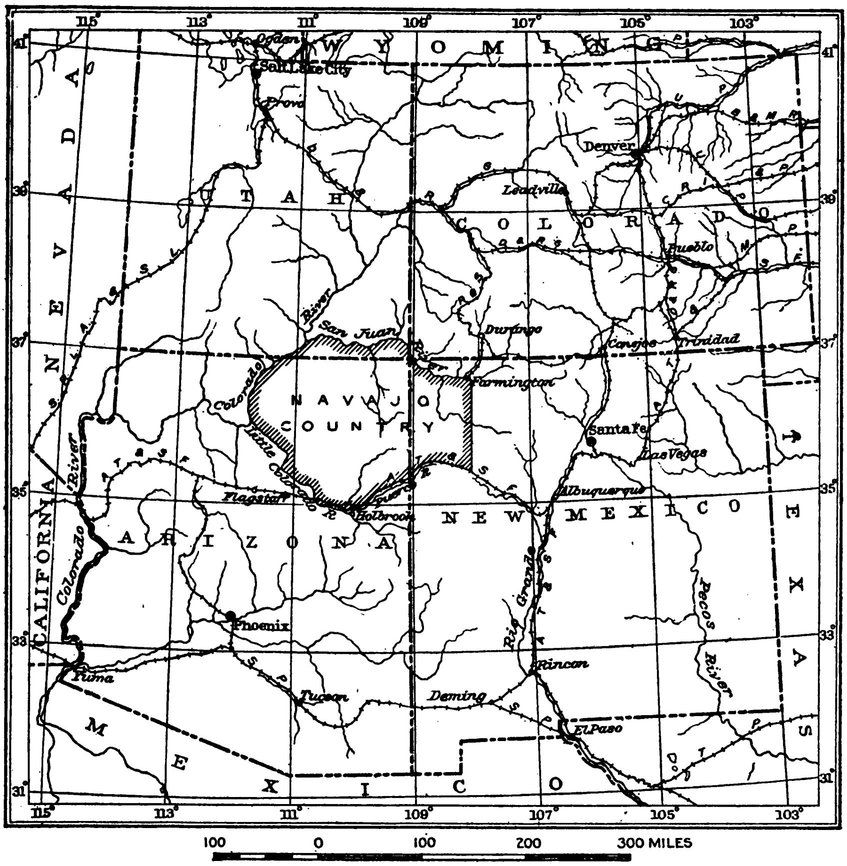

FIGURE 1.—Map showing location of area considered in this report.

not specifically set aside for the Indians, are in part allotted to them and in still larger part utilized by them, and the district covered by the map, bounded by San Juan, Colorado, Little Colorado, Puerco, and San Jose rivers and the 108th meridian, has long been known as the "Navajo country." That term is used in this report to cover the entire area represented by the map. As thus outlined the Navajo country contains 25,725 square miles—an area that is larger than the State of West Virginia and that constitutes the most extensive tract of undeveloped reservation land within the United States.

The following reconnaissance maps, made by the United States Geological Survey in 1882–1886, were used as the base for the present map: Echo Cliffs, Marsh Pass, Canyon de Chelly, San Francisco Mountain, Tusayan, Fort Defiance, Holbrook, and St. Johns, Ariz.; Escalante, Henry Mountains, and Abajo, Utah; Chaco and Wingate, N. Mex. Manuscript maps made for the War Department and for the Office of Indian Affairs have been consulted, as well as published maps from other sources. In so far as the map differs from those previously published it embodies the results of my four seasons' field work. Since the publication of maps made by the Survey this region has undergone many changes, and an effort has been made to record those brought about by man and also to represent with a greater degree of accuracy the position and character of surface and ground water supplies. Many new names have been added to the map, and in selecting them the following rules were adopted: Use all names found on older maps and in the writings of earlier explorers, so far as such names have been applied to features whose position has been determined; Navajo and Hopi terms so far as they have definite application; terms in common use by Mexicans and white men; and terms that have been applied by archeologists who have written of the Navajo country. In the spelling of Indian names care has been taken to approach as nearly as possible the native pronunciation without introducing needless complications; for Spanish terms the ordinary rules of that language have been followed. To facilitate description it has been found advisable to outline and name a number of geographic provinces and many prominent topographic features. For such names descriptive terms have been used, and also names of early explorers and of other men who have been connected in some fundamental way with the history of the Navajo country. Detailed information regarding geographic terms and their application will be found in Part IV (pp. 199–208).

It is too much to hope that the map (Pl. I, in pocket) as presented has a high degree of accuracy, but I believe that it will be found useful by those whose interests call them to this fascinating region.

HISTORICAL SKETCH.

After the occupation of central Mexico by the Spanish in 1514, exploring parties were sent northward toward the Rio Grande and the Gila. The first of these expeditions, under Niño de Guzmán (1530), succumbed to the hardships of travel on the arid plateau without reaching the present Mexican border. When Álvar Núñez Cabeza de Vaca arrived at Mexico City after his six years' memorable wanderings along the Gulf coast through Texas and southern New Mexico, bearing reports of gold and silver, turquoise and emer-

alds, elaborate plans for exploration were earnestly considered.[1] But though the lure of sudden wealth aroused the enthusiasm of officials and soldiers alike, the saner minds hesitated to weaken their hold on Mexico by dispatching large bodies of soldiers into unknown desert regions occupied by hostile tribes. At this crisis the church stepped in. Marcos de Niza, a Franciscan friar, obtained permission to depart on the long journey to the north with the hope of enrolling an unknown people under the banner of the church. Accompanied by three other priests, the Barbary negro Estevanico, and a small body of soldiers, Fray Marcos reached Zuni by way of Sonora and western Arizona. A careful reading of Fray Marcos's diary gives little basis for the cupidity excited by his narrative, but to minds already warped by lust of gold and conquest the picturesque descriptions of the Indian spokesmen became literal accounts of fact, and plans were made to conquer and convert this marvelous country of wealthy towns. Thus originated the well-known expedition of Francisco Vázquez de Coronado, president of New Spain, who in 1540 organized a well-equipped band of soldiers, priests, and wealthy adventurers, supported by two ships heavily laden with supplies, which were to ascend the Rio de Tizon [Colorado] and await the expedition near the thirty-sixth degree of latitude.[2] After innumerable hardships and discouragements the remnant of this cavalcade, spurred on by the imaginary tales of Friar Marcos, reached Cibola [Zuni], only to recoil in disgust at finding a group of squalid houses perched high on a rock mesa. In the words of the faithful historian of the expedition, Pedro de Castañeda de Nagera: "The army broke forth with maledictions on Friar Marcos de Niza; God grant that he may feel none of them!"[3] From Zuni expeditions were sent out in various directions, two of them into the region now known as the Navajo and Hopi reservations. The first expedition (1540), under Friar Juan de Padilla and Don Pedro de Tovar, discovered the Province of Tusayan, consisting of seven villages similar to Zuni, and gave the civilized world its first knowledge of the unique group of Hopi clans. It is interesting to note that among the presents made to the conquerors were tanned skins, piñon nuts, native fowl, turquoises, corn, and cotton cloth. The information gained at Tusayan was used in equipping a second expedition, under Don García López de Cárdenas, which was sent

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[1] The journal of Álvar Núñez Cabeza de Vaca, 1528–1536, translated by Fanny Bandelier, edited by A. F. Bandelier, A. S. Barnes & Co., 1905.

[2] The most accessible English edition of the original Spanish reports, by Coronado and his followers is "The journey of Coronado, 1540–1542, translated and edited by George Parker Winship," A. S. Barnes & Co., 1904. See also Hodge, F. W., Narrative of Coronado's expedition by Castañeda: Spanish explorers in the southern United States, pp. 275–287, Scribner's, New York, 1907.

[3] The story of Coronado's expedition as written by Castañeda is the most direct and trustworthy of all documents relating to this period of Spanish exploration. (See p. 208.)

out to the northwest, probably along the ancient Hopi trail. After 20 days' marching through desert lands this party came to a great river whose banks extended "three or four leagues into the air" and were "broken into pinnacles higher than the tower of the Cathedral of Seville." Because of its red, muddy waters, this stream was christened Rio Colorado. There can be little doubt that Cárdenas was the first white man to see the Grand Canyon, but his exact viewpoint probably will never be known, for the recorded description is applicable to almost every cliff face between the mouth of Grand Wash and the head of Marble Canyon. The time consumed by Cárdenas in making this journey was ample to reach any point on the canyon rim. Without further attempts to explore the country north of the present Santa Fe Railway line, Coronado's party passed eastward through Acoma, Laguna, and the pueblos along the Tiguex [Rio Grande]. After excursions eastward beyond Santa Fe the expeditions, discouraged in mind and diminished in numbers, returned to New Spain [Mexico] over the route by which they had entered the country.

After the lapse of more than 200 years, interspersed with desultory missionary and trading enterprises, the Hopi region was again visited by devoted scouts of the church. In 1776 Fray Garcés,[1] whose name is inseparably linked with missionary enterprises in the Gila and San Gabriel valleys, arrived at Tusayan [Hopi villages], where he spent several weeks before starting on the return journey to Yuma. During this same year (1776) Hernando d'Escalante Fontañeda, a zealous priest, made his memorable journey from Santa Fe through southwestern Colorado and eastern Utah, returning to the Spanish settlements across the present Western Navajo Reservation to Hopi and Zuni. Tradition states that Escalante crossed the Glen Canyon section of the Colorado at a point designated on the map as the "Crossing of the Fathers." If this is true, Escalante should be credited with the most daring adventure of all the early explorers, for this route presents formidable difficulties. As is to be expected, the diaries and letters of these early Spanish fathers contain meager information regarding the country and its people, except in matters relating to religious enterprises.

The century following the exploits of Garcés and Escalante has left little recorded history of Spanish missionary activity among the Hopis and Navajos. Travel and study were, however, continued by the priests, and accounts of more or less scientific value have appeared from time to time. In 1860 the results of seven years' travels and studies in the Southwest were published in a two-volume work

[1] Coues, Elliott, On the trail of a Spanish pioneer—The diary of Francisco Garcés, 1768–1776, 2 vols., 1900.

by Abbé Domenech. Though cluttered with far-fetched philosophic and archeologic theories, this book has value as an attempt to interpret Navajo and Pueblo customs and industries in the light of physical environment. Fauna, flora, and water supply are discussed in detail, and a description of Little Colorado River from its source to Tanner Crossing is given for the first time. The best traditions of the Roman Catholic Church are maintained by the Franciscan fathers at St. Michaels, from whose press have come two notable publications.[1]

The barrenness of the country, combined with the hostility of the Indians, has sufficed to make northeastern Arizona an unprofitable field for trapper and prospector, and the influence of these pioneers, who have played so prominent a part in other regions of the West, has left little trace on the history of the Navajo country.

Much geographic material was collected by the numerous military expeditions directed against the Navajos between the years 1845 and 1860, but nearly all of it remains unpublished. In a report of Capt. Doniphan's expedition[2] may be found the first recorded descriptions of Tchensca [Chuska] Mountains, the Canyon El Challe [de Chelly], and Laguna Colorada [Red Lake] north of the present Fort Defiance. In 1850 Simpson's report of an expedition into the Navajo country was issued by the Government.[3] I have followed Simpson's route through Washington Pass, along the Sierra de Tumecha [Tunitcha Mountain] and Chuska Mountain, along the Canyon de Chelly, past the present Fort Defiance to Puerco River, and found little to add to the descriptions of topography, fauna, flora, and climate.

Influenced by the creation of the Territories of New Mexico and of Arizona by congressional enactment in 1850 and 1863, respectively, and by the increasing importance of California, the demand for suitable wagon roads and for a railroad through the Southwest became insistent. The most feasible location for a transcontinental line was by no means evident, and many topographic surveying parties under military escort were sent into the region embracing Colorado, Utah, Nevada, Texas, New Mexico, Arizona, and California. During the years 1851 and 1852 Capt. Sitgreaves,[4] with Lieut. Parks, topographer, and Dr. S. W. Woodhouse, naturalist, under the guidance of Antoine Leroux, mapped a route from Zuni along Zuni River, down the Little Colorado to Grand Falls, and thence westward through the San Francisco Mountains to Colorado River above the mouth of the Mohave.

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[1] An ethnologic dictionary of the Navajo language, 1910. A vocabulary of the Navajo language, vol. 1, English-Navajo; vol. 2, Navajo-English, 1912.

[2] Hughes, J. T., Doniphan's expedition, 1847.

[3] 31st Cong., 1st sess., Ex. Doc. 64, pp. 55–168, plates and maps appended, 1850.

[4] Report of an expedition down the Zuni and Colorado rivers: 32d Cong., 2d sess., Ex. Doc. 59, 1854.

The 12 large volumes of the report on the Whipple expedition[1] contain the results of one of the most elaborate field reconnaissances ever undertaken by the Government. The geographic descriptions of the southern edge of the Navajo Reservation are unusually complete. The rail route recommended by Whipple extends from Albuquerque, N. Mex., through Laguna, over the Continental Divide at Campbell Pass, down the Puerco to the Little Colorado, and across the Little Colorado to Flagstaff, Ariz., and westward. Along this line the Atlantic & Pacific Railroad, now the Atchison, Topeka & Santa Fe, was constructed in 1883. A geologic map of the route and a chapter on the geology by Jules Marcou[2] constitute the first geologic studies of any part of the Navajo country.

Unlike the other exploratory expeditions which were sent into Arizona from the east, the party commanded by Lieut. Ives (1857–58)[3] ascended Colorado River in boats as far as possible. Leaving the river at Diamond Creek, Lieut. Ives, with J. S. Newberry, geologist; F. F. W. von Egloffstein, topographer; and H. B. Mollhausen, artist, traveled eastward to the Rio de Liño [Little Colorado], below the present site of Winslow, and thence proceeded to Oraibi and eastward along the well-marked trail to Pueblo Colorado [Ganado], and Fort Defiance. Newberry's comments on the geology of the route traversed, together with the geologic map of a strip from Oraibi to Fort Defiance, call attention for the first time to the presence of widely extended Cretaceous and Triassic sediments in the Navajo country and to the salient features of the Defiance monocline.

Newberry also served as geologist to the Macomb expedition (1859) into Colorado and Utah, which on its return followed San Juan River from a point near the present site of Bluff, Utah, to Canyon Largo. In the map, text, and sections published in the Macomb report the areal extent of the Mesozoic formations is outlined. The fossils collected were described and figured by Meek and Newberry. Though the scientists of the Macomb expedition confined their work to the north bank of the San Juan, beyond the area covered by the present report, the map published contains all available topographic data and records the first attempt to represent the entire area now occupied by the Navajo Reservation.[4]

[1] Whipple, A. W., Report of explorations and surveys to ascertain the most practical and economical route for a railroad from the Mississippi River to the ocean, 1853–54, Washington, 1856.

[2] Résumé of a geological reconnaissance from the junction of the Arkansas with the Mississippi to the Pueblo of Los Angeles in California: Whipple's report (cited above), vol. 3, pt. 4; published also in Geology of North America, Zurich, 1858.

[3] Ives, J. C., Report upon the Colorado River of the West: 35th Cong., 1st sess., Ex. Doc., 1858.

[4] Newberry, J. S., Geological report of an exploring expedition from Santa Fe, N. Mex., to the junction of the Grand and Green rivers of the Great Colorado of the West in 1859, under the command of Capt. J. N. Macomb, 148 pp., 11 pls., Washington, 1876.

The loosely written account of an expedition conducted by Beale[1] down Black Creek and the Puerco to the Little Colorado and beyond is interesting chiefly because of its statement that camels were used as pack animals and found to be entirely satisfactory.

The geologists of the Wheeler Survey[2] visited the southern and western portions of the Navajo country. Marvine and Howell described the route along the Little Colorado Valley, chiefly with reference to the geology. The traverse of Howell from the Little Colorado to Fort Defiance by way of the Hopi villages added stratigraphic and structural details to the account of Newberry, who followed essentially the same route. The investigations of Oscar Loew,[3] mineralogist and chemist of the Wheeler Survey, dealing with conditions affecting grazing, water supply, and fuel, though limited in scope, are of direct geographic value.

A reconnaissance map of the Carrizo Mountains was made in 1875 by Holmes,[4] who included in his report one of those unique panoramic sketches for which he is famous.

Two reports by Dutton relate to portions of the Navajo Reservation. The well-known volume on the Grand Canyon[5] includes a map of the Permian, Triassic, and Jurassic strata along Echo Cliffs; and the report on the Zuni Mountains[6] contains an account of the scenery and geology of Dutton Plateau and locates the Tertiary and igneous deposits of Chuska Mountain.

The results of recent geologic expeditions along the borders of the Navajo Reservation have been issued by the United States Geological Survey. The studies of Ward[7] in 1899 and 1901, in the Little Colorado Valley, resulted in a stratigraphic table in which, for the first time, the terms Moencopie, Lithodendron, and Leroux are introduced. The reconnaissance traverses of Schrader[8] and of Shaler[9] in northwestern New Mexico revealed the presence of an extensive coal field, which has been examined more fully by Gardner.[10]

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[1] Beale, E. F., Surveys for a wagon road from Fort Defiance to the Colorado River: 35th Cong., 1st sess., House Ex. Doc. 124, 1858.

[2] Wheeler, G. M., U. S. Geog. and Geol. Expl. W. 100th Mer. Rept., vol. 3, Geology, 1873.

[3] Idem, pt. 6.

[4] Holmes, W. H., Geological report on the San Juan district: U. S. Geol. and Geog. Survey Terr., Ninth Ann. Rept. (for 1875), pp. 237–276, pls. 34–49, 1877.

[5] Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, 1882.

[6] Dutton, C. E., Mount Taylor and the Zuni Plateau: U. S. Geol. Survey Sixth Ann. Rept., pp. 105–198, 1885.

[7] Ward, L. F., Status of the Mesozoic floras of the United States: U. S. Geol. Survey Mon. 48, pp. 37–41, 1905.

[8] Schrader, F. C., The Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 285, pp. 241–258, 1906.

[9] Shaler, M. K., A reconnaissance of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 375–426, 1907.

[10] Gardner, J. H., The coal field between Gallup and San Mateo, N. Mex.: U. S. Geol. Survey Bull. 341, pp. 364–378, 1909.

It will be noted that the geologic studies in northeastern Arizona, northwestern New Mexico, and southeastern Utah have been confined heretofore to the borders of the Navajo and Hopi reservations, except for the traverses of Newberry and of Howell along the latitude of Fort Defiance. My own work, designed to cover those portions of the Navajo Reservation which had not been previously examined by scientific parties, was begun in the spring of 1909. Since that date several papers have appeared.[1] Darton's reconnaissance is of general interest, for it was essentially a reexamination of the route traversed by Whipple, Beale, and other explorers and therefore substantially replaces the publications of previous workers along the line of the Santa Fe Railway.

TOPOGRAPHIC OUTLINE.

In its larger topographic relations the Navajo country is part of the Colorado Plateau province, a region of flat-lying or slightly tilted rocks cut by canyons and surmounted by mesas and buttes. About 32 per cent of the Navajo country lies between 6,000 and 7,000 feet above sea level, and 10 per cent between 7,000 and 9,000 feet. Only 156 square miles out of a total of 25,725 square miles lies below 4,000 feet, and only 42 square miles exceeds 9,000 feet. The extremes of relief are Navajo Mountain, 10,416 feet, and the mouth of Little Colorado River, 2,800 feet above sea level. Along the line of Bridge Canyon an extreme range in elevation of 7,000 feet is attained in a distance of 8 miles. Broadly characterized, the region is a plateau in which the depth of canyons about equals the height of mountains; in other words, the downward departures from a general surface at about 5,500 feet are nearly equal in amount to the upward departures. Two of the mountain masses, Carrizo and Navajo, are laccolithic in origin and rise domelike above the surrounding country. Chuska Mountains, Black Mesa, and Segi Mesas are essentially mesas slightly modified by folding of strata and are bordered by sheer cliffs of commanding proportions. Mesas of the second and third order and innumerable buttes, of both igneous and sedimentary origin, are characteristic features of the country. Mesa, butte, volcanic neck, canyon, wash, repeated indefinitely, are the elements of the Navajo landscape. Alcoves, recesses, and miniature

[1] Darton, N. H., A reconnaissance of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, 1910.

Campbell, M. R., and Gregory, H. E., The Black Mesa coal field, Ariz.: U. S. Geol. Survey Bull. 431, pp. 229–238, 1 pl., 1911.

Gregory, H. E., The San Juan oil field, San Juan County, Utah: U. S. Geol. Survey Bull. 431, pp. 11–25, 1 pl., 1 fig., 1911.

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erosion forms of great variety and rare beauty stand as ornamental carvings on the larger architectural features, and over all is spread an unevenly developed sheet of wind-blown sand.

So numerous and so closely interlaced are the canyons in some portions of this singular region that they have displaced all but scattered remnants of the original plateau, leaving narrow walls, isolated ridges, and spires so slender that they seem to totter upon their bases, shooting up to an enormous height from the vaults below.[1]

The main surface slopes of the country descend northward to the San Juan and southward to the Puerco and Little Colorado from a dividing line extending from Dutton Plateau to Echo Peaks. Down these slopes the surface drainage is carried in broad washes, here and there trenched by sharply cut canyons. About 14,000 square miles of the area under discussion drains into the San Juan; the Little Colorado receives water from about 9,900 square miles; and 1,880 square miles is directly tributary to the Colorado by way of the deep canyons that traverse the Rainbow Plateau. Topographic features of all grades show the influence of aridity. The stream channels are generally without water, yet enormous accumulations of coarse alluvium, the product of floods, are to be seen on all sides. In many places bedrock is swept clean by winds; elsewhere it is covered with dunes; talus slopes are in general replaced by bare rock walls. The desert, however, is a "painted desert." The gray tones of many other regions are lacking. In their place are reds and browns, blues, and greens, in masses miles in extent, or mingled to form the "variegated shales" of the earlier explorers. To those unaccustomed to desert lands the Navajo country presents in form and color and grouping of topographic features a surprising and fascinating variety; those familiar with arid regions will find here erosion features of unusual grandeur and beauty.

GEOGRAPHIC PROVINCES.

BASIS OF SUBDIVISION.

The Navajo country is too large and too diversified an area to be treated as a geographic unit. Only in the broadest sense are the various parts of the reservations alike, and the discussion of problems of water supply will be better understood when local geographic conditions are kept in mind. It has therefore been found advisable to divide the country into geographic provinces or subprovinces suggested by topography, vegetation, and other features, which have influenced the manner of life of the native population. The provinces thus outlined, 22 in number, are briefly described on the following pages.

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[1] Ives, J. C., op. cit., p. 6.

DUTTON PLATEAU.[1]

The south face of Dutton Plateau is a line of recessed cliffs which bound the flat-floored valley extending from Bluewater, N. Mex., westward across the Continental Divide at Campbell Pass.[2] This border wall of bright-red massive sandstone, rising 600 feet above a base of purple shales and limestones and continued upward by the greenish-white towers of Navajo Church, is one of the most admired scenic features along the Santa Fe route. Back of the two giant steps of Powell Mountain the plateau surface descends gently, opening up a mesa-dotted valley 3 to 5 miles broad and 50 miles long. North of this inner valley the plateau character is again assumed for a distance of 10 miles, at which point the northern bounding wall of Dutton Plateau may be descended by a series of short steps to Chaco Plateau, 600 feet below. From a distance the west border of the plateau also appears to rise abruptly, but a nearer view reveals foothills and wide canyon floors interrupting the mural escarpment. Throughout its extent Dutton Plateau maintains an average height of about 7,500 feet. Innumerable detached mesas rise above this level, and Powell Mountain and Hosta Butte culminate at 8,861 and 8,837 feet, respectively. From selected viewpoints, as Hosta Butte and Pyramid Butte, prominent topographic features of the surrounding country are revealed in a panorama, including the forest-covered Zuni Mountains, the volcanic pile of Mount Taylor, the Chaco Plateau stretching northward to the San Juan, the white face of Chuska Mountain, and the varied features of the Manuelito Plateau on the west.

Dutton Plateau is drained westward by the Puerco into the Little Colorado, and northward to the San Juan through Chaco Canyon or along the poorly marked channels of Chuska Valley. The waters from about 120 square miles are carried eastward by the San Jose into the Rio Grande. Short spring-fed streams are to be found in Satan Pass and in several of the canyons that notch the northern and northwestern face of the plateau. Four permanent lakes, including the artificial pond at Smith Store, and a number of ephemeral water bodies supplement the water supply obtained from 15 or 20 springs. Some of the springs rise from Mancos shale, and their waters are unpleasant to taste but not unwholesome. Piñon and juniper, with scattering yellow pines, are interspersed with sage and greasewood on the lower slopes, and on the higher mesas form continuous forests which are interrupted by grass-floored parks.

[1] Named in memory of Capt. Clarence E. Dutton, whose report on Mount Taylor and the Zuni Plateau (U. S. Geol. Survey Sixth Ann. Rept., pp. 105–198, 1885) includes the first interpretation of the geology of this plateau.

[2] Named in honor of its discoverer, A. H. Campbell, topographer of Whipple's expedition, 1853–54.

Grass covers the plateau in sufficient amount to provide grazing for many sheep, and the water from various sources suffices to enable the Indians to use the forage, even during the dry season. Soil weathered from Cretaceous shales and sandstones has accumulated on the flatter slopes and valley bottoms and readily responds to agricultural treatment. Many small Navajo cornfields were noted. Undeveloped coal beds are widely distributed over the plateau.

Trading posts at Smith Lake, Dalton, Navajo Church, and two other points on the plateau, together with stores along the railroad, supply the simple needs of the Indian. Crown Point, reached from Thoreau by way of San Antonio Spring and picturesque Satan Pass, is the administrative center for the Pueblo Bonito Reservation, and is provided with school, hospital, and stores.

CHACO PLATEAU.

From the base of the north wall of Dutton Plateau the Chaco Plateau extends northward to San Juan River. Westward it descends by low, broad steps to Chuska Valley, and its eastern border is marked by the line of elevated mesas adjoining Canyon Largo beyond the limits of the area studied. Its surface maintains an elevation of 5,500–6,500 feet, with a general slight slope toward the San Juan. Many low, flat tables of horizontal rock diversify the surface, and isolated buttes form prominent landmarks. The valleys are prevailingly wide, flat-floored swales, trenched by shallow, sharp-cut canyons. Even the Chaco and the Gallego valleys, which drain the plateau and present formidable canyons at their headwaters, develop open floors and sides broken into masses of low hills along their lower reaches.

Chaco Plateau is for the most part bare of trees, except for clumps of piñon and juniper, but it is well supplied with grass and admirably adapted for stock raising. A number of small lakes contain water throughout the year, and most of the wells sunk have proved satisfactory. The results obtained in irrigated gardens and small fields attest the fertility of the soil. Numerous ruins in Chaco Canyon and its branches, including the famous Pueblo Bonito at Putnam, point to a long occupation by an agricultural race. Wells for oil in the Seven Lakes region may yet prove of commercial value, and the coal included in the Cretaceous sandstone remains an undeveloped asset.

CHUSKA VALLEY.

Between the Dutton and Chaco plateaus on the east and the mountains along the New Mexico-Arizona boundary is the wide, open lowland that has received the name Chuska Valley. Its length from the Puerco divide to the San Juan is 85 miles and its width

varies from 10 miles near its head to nearly 40 miles in the latitude of Carrizo Mountain, the average being about 15 miles. The gradient of the valley floor, about 10 feet to the mile, is broken at many points by wide alluvial flats and short stretches of canyon, and in places the stream channels are obliterated by wind-blown sand. In geologic structure Chuska Valley is a syncline composed of stratified sandstones, shales, and coals. The western limb rises by regular gradation to the summit of the Chuska Mountains; the east side of the valley is marked by a labyrinth of broken mesas, flat-topped ridges, and low hogbacks eroded into fantastic knobs and pinnacles. Besides the clusters of low mesas two prominent hogbacks, one crossing the San Juan at Liberty, the other, facing Carrizo Mountain, rise from the valley flat to heights of 1,000 feet and 800 feet, respectively. Of several igneous dikes and necks which rise abruptly from the broken floor, Bennett Peak (Pl. III, *A*) ("Peaks of the Ojos Calientes"[1]) and Shiprock[2] (Pl. III, *B*) have long served as landmarks. In fact Shiprock, which thrusts itself into the air to a height of 1,400 feet above its base, is one of the most remarkable igneous masses to be found in the Southwest.

Redrock Valley (Navajo, Tselichi) lies between Lukachukai and Carrizo Mountains. Unlike the main Chuska Valley, to which it forms a sort of tributary bay, its floor is carved in colored rocks of Triassic and Jurassic age and traversed by many short, bare-walled canyons arranged according to an intricate pattern. Many springs and a few short streams emerge from canyoned recesses only to lose their way before joining Standing Redrock Creek and Black Horse Creek, which carry the flood waters through Red Wash to the San Juan.

The run-off from 5,790 square miles is drained through Chuska Valley to the San Juan, but as none of the twenty-two large and over one hundred small tributaries supply a continuous stream, the valley is dry during a large part of the year. Springs along the valley axis serve for watering places on the long road from Gallup to Shiprock and determine the location of stores. To recover the large underflow in the gravel-floored washes a number of successful shallow wells have been dug. The geologic structure is favorable also for flowing wells, and development of water by wells would enable Chuska Valley to support two or three times the present Indian population.

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[1] Simpson's map, 1857.

[2] Erroneously named Wilson's Peak on the Land Office map. This dike or neck of basic rock attracted the attention of Newberry (1859), who saw it from the north side of the San Juan at a distance of 10 miles. On Newberry's map the term "Needles" is used. Holmes, in his report on Carrizo Mountain (1877), also speaks of the "Needles," "a mass of volcanic rock which terminates in a cluster of needlelike points or spires." The term applied by Newberry and by Holmes has been discarded and Shiprock is now universally used. The name is peculiarly applicable, since the rock has the appearance of a ship under full sail. The Navajo name, Tsebidai, signifies "the winged rock."

The flora of sage and of greasewood is interspersed with solitary piñons and junipers, which become plentiful along the valley sides. Grass is of good quality and fairly abundant, except near the permanent watering places. Groups of Navajos have more or less permanent habitations along the tributary washes, and by means of dry farming supplemented by flood irrigation raise crops of corn.

Trading posts have been established at Sheep Spring, Crozier, Tuntsa [Captain Tom's Wash], Noel's, Redrock, and Biltabito, and these, with missionary establishments at Tohachi, Liberty, Jewett, and Toadlena, the stores and Government school at Tohachi, and the fully equipped agency at Shiprock on the San Juan, complete the list of stations where Navajos and whites come into contact. A wagon road traversing the valley joins Gallup with the towns on the San Juan; roads also run from Fort Defiance to Tohachi, and connection with the upper Black Creek Valley may be made by way of Washington Pass.

MANUELITO PLATEAU.[1]

The series of flat-topped hills outlined by the 7,000-foot contour and lying between Puerco River and Chuska Mountain may be grouped under the name of the Manuelito Plateau. In this area the high points are remnants of horizontal sandstone beds and are usually sharply defined by cliffs on all sides. The valleys are broad, open, flat-floored washes, in many places trenched by narrow arroyos cut in material which covers the rock floor. The valley slopes are gentle, and gullies rather than hills impede progress. Piñon and juniper with yellow pine clothe the mesas; sagebrush and greasewood cover the lower slopes, and a variety of rank weeds have obtained possession of the sand and adobe flats to the exclusion of forage plants. Tracts of the most valuable timber have been set aside as national forests. Grass, though limited in quantity and much overgrazed, is fairly satisfactory in normal seasons, but water is very scarce. Between the railroad at Gallup and Fort Defiance (35 miles), along the most generally used road in northern New Mexico and Arizona, only one permanent water supply (Rock Spring) is to be found. Sheep raising occupies the time of the Navajo inhabitants. A few farms have been located near the railroad by the whites; and the extensive mining operations near Gallup give employment to several hundred men. Coal for Fort Defiance and St. Michaels is also mined at the western edge of the plateau.

[1] Manuelito was a famous Navajo chief who rendered helpful service to the exploring parties of early days.

A. BENNETT PEAK AND VICINITY.

Typical view in middle Chuska Valley.

B. SHIPROCK AND VICINITY.

Typical view in lower Chuska Valley. Photograph by M. K. Shaler.

CREST OF WASHINGTON PASS, CHUSKA MOUNTAINS, LOOKING EAST.

Photograph by Mrs. H. E. Gregory.

CHUSKA MOUNTAINS.

NOMENCLATURE.

Along the New Mexico-Arizona boundary lies a range of mountains which extends from the mesas of Manuelito Plateau northward to Redrock Valley. Though essentially uniform in geologic structure and topographic expression, it is separated in the minds of the Navajos into a number of indefinitely outlined parts. In the earliest map of this range (Simpson, 1851) the northern portion is labeled "Sierra de Tumecha," and the part south of Washington Pass, "Sierra de Chusca." This practice was generally followed by map-makers connected with military expeditions until the publication by the United States Geological Survey of the Canyon de Chelly topographic map in 1892. On the map of that date a third division of the range—"Lukachukai"—was added to "Choiskai" and "Tunitcha." These terms were supposed to embody Navajo usage, which they do in a broad sense. The lack of topographic significance of the terms is shown by translation. Lukachukai means patches of white reeds; Tunitcha, large or much water; and Chuska, white spruce. My Navajo guides informed me that these terms refer to particular spots rather than to areas, a reasonable explanation in view of the fact that on each of the subdivisions of this continuous range spruce and reeds are to be found in several localities, and that each is about equally well supplied with both lakes and running streams.

In the introduction to an ethnologic dictionary of the Navajo language, published by the Franciscan fathers of St. Michaels, Ariz., in 1910, the northwestern end of the range is called "Lukachukai Mountains," the central part is called the "Tunicha Range," and the southeastern end the "Chuska Range." In a report on life zones and crop zones of New Mexico, Vernon Bailey[1] applies the name "Chusca Mountains" to the entire range, giving the following information in a footnote:

> The name Chusca, or Choiskai, is generally applied to the southern half, and Tunicha, or Tunitcha, to the northern half of this perfectly continuous and nearly uniform range. There is certainly not room for two names, and I have used the one that seems better known and in its shorter form, which is in common use among local residents.

This use of Chuska for the entire range has been approved by the United States Geographic Board, but the subdivisions Lukachukai, Tunitcha, and Chuska are retained for purposes of description as well as for historical reasons.

[1] U. S. Dept. Agr. Bur. Biol. Survey North Am. Fauna No. 35, p. 60, 1913.

EASTERN EDGE.

The eastern flank of the Chuska Mountains is an imperfectly graded slope which rises from Chuska Valley at the rate of 200 to 300 feet per mile up to the 8,000-foot contour, above which steep and frequently precipitous cliffs extend to the edges of the plateau-like summit. Stream channels, spaced 1 mile to 3 miles apart, gash the surficial débris and in places cut into bedrock. Many of these channels contain water in their upper courses, and a line of springs, each surrounded by a small meadow, is found near the base of the upper cliffs. The slopes are covered with piñon and juniper, with alder, willow, and aspen along the short streams, and oaks and a few magnificent yellow pines along the higher benches above 7,000 feet. The scrub oak attains sizes up to 15 inches in diameter and is plentiful enough for corrals and house timbers; pines 8 inches to 2 feet in diameter were noted.[1]

The Navajos here are prosperous; they raise corn, wheat, potatoes, and garden truck, and bale hay for market by pressing it into holes in the ground and tying with yucca or willow withes. Several well-made log cabins were noted between Tohachi and Washington Pass. The Indians along the east base of the Chuska Mountains have ready access to the school and subagency at Tohachi, the Mission station at Toadlena, as well as the stores in Chuska Valley. Numerous trails, in addition to the wagon road through Washington Pass,[2] lead to Crystal and to Fort Defiance.

WESTERN EDGE.

Unlike the eastern border of the Chuska Mountains, their western edge presents a nearly vertical escarpment, continuous except for the mouths of numerous canyons which reach into the heart of the mountains. Another distinguishing feature is the type of drainage. Most of the streams scarring the eastern flank rise on the immediate rim and collect little water from the mountain top; those flowing west extend nearly across the mountain summit. Because of this enlarged drainage area the streams emerging from the red bounding cliff wall are perennial. Upper Black Creek, Simpson Creek,[3]

[1] Simpson (1850) mentioned pine trees 8 feet in circumference and 80 feet high.

[2] This pass, named by Simpson in honor of Lieut. Col. John M. Washington, governor of New Mexico and commander of the "Expedition against the Navajos" in 1849, is definitely located on Simpson's map and figured as plate 45 of the official report. The location of Washington Pass on the Canyon de Chelly topographic map of the United States Geological Survey is erroneous. The local name for this pass, "Cottonwood," is not only confusing but inappropriate, because of the absence of cottonwoods at this elevation (8,500 feet).

[3] Simpson Creek is proposed as the name of the stream rising in Washington Pass and flowing west to Black Lake. Capt. Simpson's expedition was the first party of white men to cross the Chuska Mountain by this route. The Navajo term (Besth-kli-chee-begez = stream running from two peaks) is considered too awkward for map use, and the local name "Cottonwood" has no significance.

Whiskey Creek, Palisade Creek, Wheatfields Creek, Spruce Brook. and Lukachukai Creek are beautiful streams of water, all capable of more extended use in irrigation. Prosperous groups of Navajos live on Simpson Creek and in Todilto Park (Navajo, sounding water), on upper Black Creek, where conditions for both agriculture and stock raising are very satisfactory.

The flora along the westward-flowing streams presents a variety even greater than that found on the eastern flank of the mountains. In addition to yellow pine and spruce and fir and the ever-present piñon and juniper, oaks, aspens, birch, and willows are plentiful. Hops and briars are twined about the shrubs, and flowers grow in profusion. The Indians cultivate gardens and raise patches of corn and of wheat and have a practice of fencing choice meadow lands in which native grass is allowed to reach maturity. Except for the lack of outlook no more desirable camping spots could be found. Stores at Crystal, at Greasewood, and at Round Rock supply local needs, and fairly good wagon roads lead to Fort Defiance and to Chinle.

THE MOUNTAIN TOP.

The wall forming the upper portion of the slopes flanking the Chuska Mountains rises to an altitude of about 8,000 feet. Above this point the range spreads out as a plateau with a relief of approximately 1,000 feet. The summit plateau is developed partly in Tertiary sediments and partly in lava (Pl. IV), and erosion has produced wide grass-covered valleys above which rise small mesas and irregularly shaped buttes capped by more indurated portions of the sandstone strata. Two large areas on Chuska Mountain and one on Tunitcha Mountain present flat surfaces at 8,800 to 9,000 feet. On Chuska Mountain these elevations mark the summit. The culminating points on Tunitcha Mountain are Matthews Peak[1] (9,403 feet) and Roof Butte (9,575 feet). The highest level on Lukachukai Mountain is reached at View Point (9,430 feet). From this mesa an unobstructed view may be obtained of the gorgeous panorama of Redrock Valley, Carrizo Mountain, and the lands beyond the San Juan. The Ute, La Plata, Abajo, Henry, and Navajo mountains are clearly visible; and in the middle distance are displayed the canyoned valley of the Chinle and the red-walled Monument Valley, dominated by the towering Agathla Peak. In the immediate foreground the eye rests on 14 lakes, bordered by grass and flowers and shaded by pines and oaks. This mesa is an ideal camp spot, well supplied with water, wood, and forage.

[1] Named in memory of Dr. Washington Matthews, author of many papers on Navajo anthropology.

Beyond the heads of the canyons the top of the Chuska Mountains is imperfectly drained. The streams meander through wide grass-covered floors, and swamp-bordered lakes are common. These miniature lakes, of which 41 are mapped on Chuska Mountain alone, exceed 100 in number and constitute a remarkable feature for these altitudes in the arid southwest.

The flora covering the mountain top is prevailingly yellow pine, but oak, fir, spruce, black birch, aspen, alder, and willow are common. Raspberries and wild currants are present; and among the flowers noted are roses, Mariposa lily, geranium, bluebells, wild flax, and foxglove. Grass is abundant and of good quality—a fact which makes these mountains the goal of the Navajo herdsmen when water fails in the lower lands.

CARRIZO MOUNTAIN.

Carrizo Mountain rises, a solitary mass, above the floor of the Chuska and San Juan valleys (Pl. V).[1] It is separated from its nearest neighbor, Lukachukai Mountain, by the beautiful Redrock Valley. Unlike Lukachukai and other subdivisions of the Chuska Mountains, Carrizo owes its position and form to the intrusion of igneous rock which has flexed the sedimentary strata into a dome. The top of the mountain presents a roughly flat surface at an elevation of 8,000 to 8,500 feet; other plateaus stand at 9,000 feet, and above them rise rounded peaks reaching their greatest height at Zilbetod (9,400 feet) and Pastora Peak[2] (9,420 feet). The mountain sides are gashed by valleys which reach well into the body of the mass. Near their heads these valleys are bordered by nearly vertical walls; farther down the canyons are replaced by wide-floored washes. Permanent streams occupy portions of these valleys and, together with springs perched high upon the mountain flanks, furnish sufficient water for the needs of the Navajo. Where the mountain is not overgrazed grass is found over the top and sides among thinly spread groves of yellow pine. Search for mineral wealth on Carrizo has resulted in failure, and the Navajo tends his sheep undisturbed by other interests. Stores at Tisnasbas, at the north base of the mountain, at Biltabito, and in Redrock Valley supply local needs and, with the mission at Tisnasbas, include all the white inhabitants of the Carrizo Mountain area. Until recently Carrizo Mountain was forbidden ground to the whites, but no obstacles are now placed in the way of scientists whose mission is understood by the Navajos.

[1] The Navajo name for Carrizo Mountain is the picturesque term Dzil naozili=the mountain surrounded by mountains.

[2] Named by W. H. Holmes in 1875.

CARRIZO MOUNTAIN FROM THE EAST.

Photograph by W. B. Emery.

A. SAN JUAN VALLEY AT SHIPROCK.

Photograph by W. B. Emery.

B. SAN JUAN CANYON 3 MILES BELOW GOODRIDGE, UTAH.

GOTHIC MESAS.

The area south of the San Juan, extending to the base of Carrizo and Lukachukai mountains, and included between Chuska and Chinle valleys, is cut into an intricate mass of mesas of various sizes and shapes, carved from massive red sandstone. For this geographic province the name Gothic Mesas is proposed. The complicated topographic pattern of the region was noted by Macomb, who gave the name Gothic Wash[1] to the wide-mouthed canyon which joins the San Juan above Comb Ridge. This mesa land is drained directly into the San Juan or into that river by way of the Chinle. The principal stream is Walker Creek,[2] which carries the water from more than twenty sharply cut canyons heading in Carrizo and Lukachukai mountains. Two of the upper canyons tributary to Walker Creek—Alcove and Seklagaideza—are unusually labyrinthine in character and are deeply cut into brightly colored strata, whose precipitous edges are elaborately carved into alcoves and recesses. The protection afforded by these overhanging cliffs attracted an ancient people whose ruined homes are to be seen along the canyon wall. Arido and Desert creeks are typical of the short canyons that carry flood waters directly to the San Juan. A large part of this area is floored with bare rock, swept clean by the wind. Here and there isolated piñons and fields of sage indicate the presence of soil, and along the canyon bottoms groups of Indians have sheep corrals and small patches of corn. Trading posts at Mexican Water (Nokaito), at Tisnasbas, and at Bluff supply a market for wool and blankets, the products of Navajo sheep husbandry. The old Mormon road from Bluff passes Tohanadla and Totocong springs on its way to Tyende and Tuba. Gothic Mesas may be reached from the railroad at Farmington, N. Mex., over an ancient trail now developed into an execrable wagon road.

SAN JUAN VALLEY.[3]

Between Farmington, N. Mex., and Goodridge, Utah, the San Juan occupies a flood plain 1 to 2 miles wide (Pl. VI, *A*); below Goodridge the stream follows the floor of a narrow meandering canyon, 1,200–2,500 feet deep, to its junction with the Colorado (Pl. VI, *B*). In general, tributaries from the north join the San Juan as wide-mouthed washes; those from the south occupy canyons; the arable land is therefore confined to cottonwood-covered flats on the north side of the river, and here also are the villages of Farmington,

[1] Gothic Wash as indicated on the Canyon de Chelly topographic map occupies the position of Walker Creek. On the present map Gothic Wash is given the location originally assigned to it by Macomb in 1860.
[2] See footnote, p. 90.
[3] This province is not outlined on the map (Pl. I, in pocket).

Fruitland, Liberty, Jewett, the Indian agency at Shiprock, the farmer station at Aneth, and the prosperous Mormon settlement at Bluff, Utah (Pl. VII). At a number of points along the river abandoned machinery and miners' huts mark the site of gold prospects, and the oil field at Goodridge has been extensively developed. Few Indians occupy the south bank of the San Juan west of the Colorado line. The alluvial flats on the north bank are dotted with hogans, the homes of Navajos who combine stock raising with agriculture. Along the river above the mouth of the Chinle the Navajos and Piutes are found together; from Goodridge to Piute Canyon the widely scattered families belong to the Piute tribe. Below Piute Canyon no Indians were seen, either on the San Juan or the Colorado. Cottonwood trees are found on the flood plain all along the river; piñon and junipers protrude from cracks in the canyon walls; and shrubs of several varieties occupy rock benches bordering the stream. Driftwood is piled high at favorable localities. The San Juan is spanned by a bridge at Goodridge, and a second bridge is being constructed at Shiprock. The treacherous character of the river tends to discourage crossing at points between Farmington and Goodridge. A trail at the mouth of Copper Canyon leads northward into Utah; elsewhere on the deeply intrenched lower San Juan crossing is precarious.

BLACK CREEK VALLEY.

Between the Chuska Mountains and Defiance Plateau, extending from Black Lake to Houck station, lies Black Creek Valley. The average slope of the valley floor is about 25 feet per mile for its length of 60 miles. Throughout its course it presents widely different aspects. In the vicinity of Crystal its floor is flat and occupied by ephemeral lakes. Beginning at Hunter Point the valley narrows to 1 mile, then increases in width to Oak Spring, at which point it is replaced by a red-walled canyon, 600 feet deep and less than half a mile wide, cut through the Defiance monocline (Pl. VIII, *A*). Below the canyon the valley gradually increases in width until it joins the Puerco. Black Rock near Fort Defiance, The Beast, and several other necks and dikes, at the foot of Red Lake, rise 100 to 300 feet above the valley floor and contrast strongly with the bright-colored sediments which surround them (Pl. VIII, *B*). Also above the floor of the valley rise long, low ridges of shale and mounds of variegated, friable materials, which are cut into "badland" forms. One of these ridges, behind which lies Fort Defiance, is so placed as to afford a magnificent view of the valley, including the massive red walls of sandstone displaying alcoves and curtains, the detached "haystacks," and the purple and ash-gray shales intricately carved into a fascinating variety of form. These beautifully colored strata

SAN JUAN VALLEY AT BLUFF, UTAH, LOOKING SOUTH.

A (UPPER VIEW). DEFIANCE MONOCLINE AT HEAD OF LOWER BLACK CREEK CANYON.
B (LOWER VIEW). RED LAKE, BLACK CREEK VALLEY, LOOKING SOUTHEAST TOWARD ZILDITLOI MOUNTAIN; THE BEAST (DIKE) IN RIGHT MIDDLE DISTANCE.

appear as a frame for the picturesque Zilditloi Mountain. Interesting minor features are the Natural Bridge west of Black Rock, and the well-known window southeast of Fort Defiance.

The valley is drained by Black Creek, which enters Black Creek Valley at Red Lake, 12 miles below the valley head. The water in the upper part of the valley flows out on a flat from which it escapes only at exceptionally high stages. One permanent stream, upper Black Creek, enters the valley from the east; from the west the Bonito at Fort Defiance and the Cienega at St. Michaels contribute small but constant supplies. The outlet stream from Buell Park also reaches Black Creek during part of the year. The supplies from these tributaries, supplemented by a large underground flow, serve to make Black Creek a living stream through a large portion of its course. That Black Creek Valley is fertile is amply demonstrated by the successful agriculture carried on at Fort Defiance, St. Michaels, Houck, and a few other points. The storage reservoir at Red Lake and the proposed reservoir at Oak Spring afford opportunities for more extensive development.

The flora of the valley is primarily sage, greasewood, and hardy annuals. Juniper and piñon in large numbers occupy the ridges and are sparingly distributed over the lower flats. The scant grass of the valley shows the effect of overgrazing.

In Black Creek Valley are the oldest permanent white settlements within the Navajo Reservation. Simpson[1] in 1850 appears to have first called attention to the attractive features of Fort Defiance and St. Michaels.[2] Soon after Simpson's visit Fort Defiance was established as a military post and became a way station for early exploratory expeditions, beginning with Whipple (Marcou, geologist), 1853–54. During the wars with the Navajos Fort Defiance was the center of considerable military activity, and the name of Kit Carson is closely associated with its history. At a much later date Fort Defiance became the Navajo agency from which a limited and ineffectual control over the Indians was exercised. Under the guidance of efficient superintendents Fort Defiance has become, within the last 10 years, the most influential center within the Indian country. The work of Government schools and hospitals and farms has been supplemented by the establishment of a private hospital and a Protestant mission. A Roman Catholic school and a Franciscan establishment at St. Michaels (Navajo, Tso hotso=yellow meadow, the Cienega Amarilla of the Mexicans) still further increase the civilizing influences within Black Creek Valley. The response of the Navajos

[1] Simpson, Lieut. J. H., An expedition into the Navajo country: 31st Cong., 1st sess., Ex. Doc. 64, 1850.

[2] Simpson's route from the mouth of Canyon de Chelly led past "Sandstone column" (Carson's Monument), "Cañoncito Bonito" (Fort Defiance), "Sieneguilla de Maria" (St. Michaels), and thence down Black Creek valley to Zuni.

to these opportunities is shown by the large number of permanent homes and cultivated fields distributed along the valley from Red Lake southward to the railroad.

DEFIANCE PLATEAU.[1]

The eastern border of Defiance Plateau is sharply defined by Black Creek Valley and the escarpment of Tunitcha and Lukachukai mountains. Its western boundary is the Chinle and Pueblo Colorado Valley. From Round Rock to Sanders, Defiance Plateau is nearly 100 miles long. Its average width is about 40 miles, except along Puerco River, where it is 60 miles. The plateau is essentially an elongated dome rising above a rim which stands at an altitude of 7,000 feet on the eastern border of the plateau and at 6,000 feet on the western border. The dome flattens toward the north, where the descent is gradual to 5,500 feet; at the southwest also the plateau surface drops below 6,000 feet and reaches its lowest elevation (5,200 feet) in the cliffs facing Puerco River at Holbrook. About 20 square miles of the flat summit northwest of Fort Defiance is bounded by the 7,800-foot contour. The plateau as a whole is free from mesas and buttes which interrupt the skyline, but those which are present assume unusual prominence. Round Rock (Navajo, Tsenakani), 6,020 feet high, is an example of a small group of buttes carved from massive sandstone, but most of the landmarks rising out of the plateau floor are igneous in origin. Black Pinnacle, Sezhini, and Sonsela (Navajo, twin stars) Buttes, the last named reaching 9,000 feet in elevation, are prominent features in the upper Canyon de Chelly region; and Pilot Rock (6,600 feet), northeast of Holbrook, is a landmark on the southwest edge of the plateau. The highest point (8,600 feet) on the central portion of the plateau is the well-known Fluted Rock (Navajo, Zildasaani).

Padres Mesa and other highlands overlooking the Puerco Valley, and drained by Chambers, Lithodendron,[2] Wide Ruin, and Leroux washes,[3] present long slopes leading southward and sharply truncated on their northwest edges. They are traversed on intercanyon spaces by open valleys, interrupted by areas of dunes which together form a topography without sharp relief. Bare rock is rarely exposed and soil is apparently deep.

The surface of Defiance Plateau is drained by wide, flat-floored valleys trenched by narrow, shallow canyons. The general slope of the plateau is westward, becoming southwestward at the southern

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[1] In the absence of any Navajo, Mexican, or English term now in use the name Defiance (after Fort Defiance) is proposed for this well-defined geographic unit.

[2] This name Lithodendron was applied to this wash by Whipple (1853–54), who discovered the fossil forests at this locality. Lithodendron Creek appears also on the official Army map of 1883. Whipple applied the name " Carrizo Creek " to the short wash next east of Lithodendron.

[3] Named by Whipple (1853–54) " Leroux Forks." Antoine Leroux served as guide for Whipple and for Sitgreaves.

and northwestward at the northern margins. The eastward-flowing streams tributary to Black Creek are accordingly short and carry little water; those trending westward are long and many of them are perennial. At the south, Chambers Wash, Lithodendron Wash, and the 50-mile long Wide Ruin Wash[1] are examples of valleys which have developed extensive flood plains across which wander the seasonal streams. The Pueblo Colorado and Nazlini, together with many smaller channels, traverse the western slopes in canyons 100 to 300 feet deep. The northern slope is drained by Lukachukai, Agua Sal, and Sheep Dip creeks. The largest stream on the plateau, and the one which has cut the deepest canyon, occupies the famous Canyon de Chelly,[2] and its tributary Canyon del Muerto (Pl. IX, *A*). These streams carry a large portion of the run-off from Chuska and Tunitcha mountains, which insures a permanent flow. They occupy canyons cut in red sandstone, bounded by walls 800 feet high, from which project enormous pinnacles, buttresses, and towers. In niches carved in the canyon walls stand buildings of an ancient race, which have held the attention of archeologists and explorers since their discovery by Simpson in 1850 (Pl. IX, *B*). Except at its southern end water may be found on Defiance Plateau at points rarely more than 8 to 10 miles apart, even during the dry season. Between Wide Ruin Wash and the Santa Fe Railway line permanent water occurs only at a few localities, but grass is abundant.

Forests of yellow pine cover the higher parts of the plateau and furnish the lumber locally used. With the pines are groves of scrub oak, and along the margins of the plateau piñon and juniper form continuous forests or solitary groups standing in the midst of extensive tracts of sage, which here attains a height of 4 to 6 feet. Within the canyons cottonwood, oak, and hackberry are found; and in Canyon de Chelly and Nazlini Canyon seedling peach trees form an unexpected phase of the flora. Natural agriculture, chiefly limited to the raising of corn, is practiced in Wide Ruin, Pueblo Colorado, and other washes where flood irrigation is feasible. Along Simpson Creek, Wheatfields Creek,[3] Spruce Brook, and Lukachukai Creek many Indian farms are located, and at Lukachukai the Navajos have developed the most successful farms observed on the reservation. Corn, wheat, alfalfa, potatoes, and melons are raised here, both with and without the aid of irrigation. The Government irrigation projects at Ganado and at Wheatfields are designed to in-

[1] Wide Ruin is the remains of a prehistoric "palace," 400 feet square, built across a narrow wash, and containing a rock-walled well.

[2] The orthography Canyon de Chelly (pronounced de Shay) was obtained by Simpson (Expedition to the Navajo country, p. 69) from Señor Donaciano Vigil, secretary of the Province of New Spain, who states that it is of Indian origin. The word is probably a Spanish corruption of the Navajo term Tse-yi—that is, "in the rock canyon." Tsa lee is the term applied to the head of Canyon del Muerto, an English form of the Navajo Sehili—that is, "it flows into the canyon." Chinle signifies "it flows from the canyon."

[3] Cieneguilla de Juanito of Simpson.

crease the acreage at points where agriculture is now carried on by intelligent Navajos. Trading posts on Defiance Plateau are located at Wide Ruin, Cross Canyon, Saw Mill, Nazlini, Sheep Dip, Crystal, and Round Rock, and a Government farmer is stationed at Wheatfields. The Indians, however, most frequently visit the stores at Fort Defiance, St. Michaels, Ganado, and Chinle, where schools and missions and Government officers are located. The beginning of permanent white settlement at Lukachukai is marked by the erection of a Franciscan chapel. Nearly all the Indian settlements on Defiance Plateau are now accessible by reasonably good roads. Regular mail stages ply between St. Michaels and Ganado, and the Fort Defiance-Chinle road is in constant use except during the winter, when heavy snowfalls block the way.

CHINLE AND PUEBLO COLORADO VALLEYS.

The Chinle and Pueblo Colorado washes, though carrying water in opposite directions, form a continuous valley traversing the entire width of the Navajo Reservation and separating areas of unlike character. Chinle Wash heads in a flat divide at Ganado and receives drainage from Defiance Plateau and the Gothic Mesas on the east, and from Black and Segi mesas on the west. In its length of over 100 miles it descends at the rate of 13 feet per mile from 6,700 to 4,400 feet, where it joins the San Juan. South from the divide at Ganado, the Pueblo Colorado Wash extends to the Puerco at Holbrook, dropping 1,700 feet in a distance of about 90 miles. Neither wash receives water with sufficient regularity to insure permanent flow, but the gravel floors of both carry large quantities of underground water, which comes to the surface for short stretches. During the dry season the Pueblo Colorado Wash is without water, and along its lower reaches becomes the playground of drifting sands. During normal years the Chinle is a permanent stream from the mouth of Tyende Creek to the San Juan, but its upper part becomes dry between showers. Even the Nazlini, the De Chelly, and the Lukachukai lose their waters before joining their master stream. During the rainy season and following showers both the Pueblo Colorado and the Chinle washes are flooded and in their flatter portions form shallow lakes a mile or more in width. The most reliable stream in the whole system is the Tyende, which, flowing from Marsh Pass, collects the waters from the southern part of the Segi Mesas.

The immediate valley of Chinle Wash is walled in on the west, from its head to Bekihatso Lakes, by broken mesas and gentle slopes reaching back to Black Mesa. From Bekihatso Lakes to Setsiltso there is an inner wall of limestone and shales, which forms the front of Carson Mesa. Back of the edge of Carson Mesa an intricately carved region of mesas, flat-topped ridges, valley flats and slopes ex-

A. NORTH WALL OF CANYON DE CHELLY BETWEEN CANYON DEL MUERTO AND MONUMENT CANYON.

Height of wall may be judged from size of horse and buggy in middle distance. Photograph by W. C. Mendenhall.

B. CLIFF HOUSE IN CANYON DE CHELLY AT JUNCTION WITH CANYON DEL MUERTO.

Photograph by W. C. Mendenhall.

A. PUEBLO COLORADO WASH BELOW TWIN MESAS.

Cliffs of Chinle strata.

B. VOLCANIC NECKS AT WEST EDGE OF HOPI BUTTES, ON CHANDLER'S RANCH.

tends to Black Mesa and up the Tyende to Segi Mesas. Pillars, columns, needles, and natural windows set in the midst of dunes and bare rock domes are attractive features of this little known area.

From Setsiltso Spring to the mouth of the Tyende, Chinle Creek flows through easily eroded materials in which it has cut a wide canyon which maintains a depth of 100 to 200 feet. Below Mexican Water the creek follows a canyon sunk 100 to 300 feet in massive red sandstone, and after cutting its path across Comb Ridge it joins the San Juan at grade. The Pueblo Colorado Wash nowhere assumes the proportions of a canyon, but precipitous slopes rise on its western side to heights of 400 to 500 feet (Pl. X, *A*).

The valley of Tyende Creek, the chief western tributary of the Chinle, is walled on the north by Comb Ridge, south and east of which it spreads widely until limited by broken mesas and ridges extending northeast from Black Mesa. East of Tyende School the valley is flat except for Church Rock and other igneous masses which rise abruptly from the floor. About 15 miles above its junction with the Chinle, Tyende Creek drops into a canyon with alluvial walls, which farther down are replaced by red sandstone. Between the Tyende-Chinle and Comb Ridge the Arizona-Utah line is crossed by Garnet Ridge. The surface of the ground at this locality is covered with erratics and strewn with garnets in unbelievable quantities, the source of the Arizona "rubies" of commerce.

Sage and greasewood, with scattering piñons, rare junipers, and occasional groves of cottonwood make up the flora of these washes. Forage, except along the immediate stream channels, is fairly abundant. The Navajos utilize these valleys for agriculture, relying on the seasonal rains for irrigation. Several hundred Indians grouped at "cornfields," particularly below Chinle School, along the Tyende, and between Ganado and Sunrise Springs, have made permanent homes and carry on successful agriculture. White settlements are situated at Sunrise Springs, Cornfields (6 miles below Ganado), Ganado, Chinle, and Tyende.

HOPI BUTTES.

South of Black Mesa and crossed by the southern boundary line of the Hopi Reservation, is an area of lava-capped mesas, igneous dikes and volcanic necks, which, since the days of the Spanish explorers, has been known as the Hopi[1] Buttes (Pl. X, *B*).

Topographically the area consists of a platform of sedimentary rock whose edges are exposed in cliffs facing the Pueblo Colorado and the Little Colorado. The platform is tilted slightly toward the

[1] The term Hopi is preferable to the better known Moki or Moqui. The remnants of the ancient cliff dwellers now on the reservation call themselves Hopi. Moqui is a term of derision meaning "dead ones," applied to the Hopi by the Navajo. Hopi Buttes is an older and more appropriate name for this area than Rabbit Ear Mountain, which first appeared on the Tusayan topographic map of the United States Geological Survey.

south, so that a surface elevation at the base of Black Mesa of 6,000 feet becomes 5,600 feet at Ives Mesa and Marcou Mesa, 40 miles farther south. Above this floor rise more than 100 lava-capped mesas and buttes of igneous material, from 100 to 1,200 feet in height. Volcanism has long been extinct here, and ash cones and flows of recent date, such as are abundantly displayed about San Francisco Mountain, 70 miles to the west, are absent. The walls of the washes and of the mesas, as well as of the intervalley spaces, are cut in Triassic and Jurassic shales, which favor the production of erosion features of exceptional variety. All the types of "badland" topography find here their full expression. This intricate erosion fabric, brilliantly colored and strewn with petrified wood, gives to the area a striking individuality. There are no perennial streams in the whole Hopi Buttes province, and except for the floods of August the wide washes are deserts of drifting sand. The Hopi Buttes provide good grazing, which the numerous springs issuing from the lava enable the Indians to utilize, and the juniper and piñon clothing the mesas supply materials for corrals and semipermanent hogans. The Hopi Buttes are partly outside the Indian reservation, but allotments have been made to the Navajos on general public lands, and grazing and water are reserved for Indian use.

Trading posts have long been situated at Indian Wells and at Cedar Springs, and in recognition of the growing importance of this district a Government farmer station has been established recently at Maddox (Stiles ranch, Castle Buttes), and a Protestant mission has been located at Indian Wells.

TUSAYAN WASHES.

The area south of Black Mesa and included between the Hopi Buttes and the Moenkopi Plateau is relatively simple in structure. Its principal topographic features are the four long Tusayan washes—Jadito, First Mesa (Polacca), Oraibi, and Dinnebito—which serve as channels to carry the waters from Black Mesa and the western half of the Hopi Buttes to the Little Colorado. Separating Jadito and First Mesa washes, Tovar Mesa [1] tapers southwestward, rising 100 to 400 feet above the valley floor. The flat terraced land which forms the divide between Oraibi and Dinnebito washes is wider and higher. Its southern extension, Newberry Mesa,[2] faces the Little Colorado with a 200-foot cliff; the two terraces of Garces Mesa [3] have a combined height of 800 feet; the

[1] Pedro de Tovar was the leader of an exploring party sent out by Coronado to investigate the Hopi pueblos in 1540.

[2] Named in honor of J. S. Newberry, who visited and described this mesa in 1858.

[3] Fray Garcés journeyed back and forth in Arizona and California for several years, and his experiences are related in the diary referred to elsewhere (p. 17).

isolated Padilla Mesa,[1] an outlier of Black Mesa, rises 1,000 feet above the floor of the Dinnebito Wash. All the dividing mesas descend by a series of steps to the Little Colorado, but the floors of the washes descend gradually from elevations of 5,800 feet at the Hopi villages to 4,800 feet on the flats along the river. Dinnebito Wash maintains its individuality from source to mouth, reaching the Little Colorado after a journey of 60 miles, in which distance it falls 1,400 feet. The other three washes have gentler gradients and unite at Tolani Lakes (Navajo, many waters), beyond which point their waters are carried by Corn Creek. First Mesa Wash receives accessions from Second Mesa Wash, Wepo Wash, and Keams Canyon; Jadito Wash is joined by tributaries from the northwestern front of the Hopi Buttes, and Corn Creek has direct connection with Bardgeman and Coyote washes. All these valleys are marked by alluvial floors 1 to 5 miles wide, in the midst of which sharply cut, alluvium-walled arroyos carry flood waters from flat to flat. In many places channels are absent and waters poured from narrow arroyos spread widely to form ephemeral lakes. Tolani Lakes, a group of permanent fresh-water bodies in the lower Oraibi Wash, constitute a unique feature of the topography (p. 117).

Trees are scarce in this area except on the higher mesas, but sage and greasewood are vigorous.

The northern part of the Tusayan Washes has been utilized by the Hopis since days long antedating the Spanish conquest. Corn is cultivated by flood irrigation, usually by families whose homes are in the distant mesa villages. In the southern portion of the washes and on the intervening mesas Navajos have formed nomadic settlements where the water supply permits. Roads to Leupp and to Winslow furnish an outlet to white settlements, and stores at Tolchico, Cedar Springs, Oraibi, Toreva, Polacca, and Keams Canyon, as well as along the railroad, furnish centers for trade.

MOENKOPI PLATEAU.

The triangular area bounded by Dinnebito and Moenkopi washes and the cliffs facing the Little Colorado is the least known part of the southern Navajo Reservation. From the west it is reached by ascending four terrace steps, each 400 feet high, finally attaining an elevation of 5,800 feet above sea. Howell Mesa[2] stands alone on the plateau surface, above which it rises to a height of 800 feet. At the north edge of the Moenkopi Plateau a drop of 600 feet brings one to an extensive terrace 600 feet above the Moenkopi Wash,

[1] Juan de Padilla, a Franciscan priest, discovered the Province of Tusayan (Hopi villages) in 1540 and was finally killed by the Indians in a revolt against the white people and their religion.

[2] Named in honor of E. E. Howell, who made the first geologic traverse of this portion of the Navajo Reservation.

which here flows between banks whose height equals the terrace front. The Moenkopi Plateau is drained almost wholly into the Little Colorado through deep gashes cut in the terrace steps, or into the Moenkopi through canyons, 600 to 800 feet deep, whose sides are formed of gray, green, pink, and white strata of singular beauty (Pl. XI, *A*).

Piñon and juniper, arranged in groves or standing as individuals, rise out of the sage and grass-covered floor. Ward Terrace[1] is utilized for grazing, and a few small fields west of Howell Mesa are tended by Navajos, but the plateau as a whole is little used.

The plateau is crossed by a trail and a difficult wagon road between Oraibi and Tuba, along which lies the mine which supplies coal to the Government school.

BLACK MESA.

A topographic map of the Navajo country shows Black Mesa as an island with a circumference of about 250 miles, and sharply defined on all sides by cliffs overlooking the surrounding geographic provinces. Its unity is broken toward the southeast, where Salahkai Mesa is partly disconnected and where a canyoned bordering shelf between Ganado and Keams Canyon forms a sort of lower step to Black Mesa proper. The east, northeast, and northwest sides of Black Mesa are defined by a cliff which, with minor notching, extends continuously for 110 miles, as a wall rising 1,200 to 2,000 feet above the flattened slopes at its base. The southwestern and southern margins are made extremely sinuous by the development of long, scalloped mesas, which project like withered fingers into the Tusayan washes. The mesa attains its greatest elevation facing the Chinle valley, where, for a distance of 40 miles between Yale Point and Lolomai Point, a height of 8,000 feet above sea is maintained. From this high rim the surface of the plateau descends gradually to the south and southwest until its average elevation is 6,500 feet. A few detached messas, as Zillesa and Ziltahjini, rise above the surface, but in general the plateau presents an even sky line broken by wide flattened valleys in the floors of which shallow rock canyons have been cut. The upper Moenkopi valley is an exception to the rule, and presents a formidable canyon, 400 to 600 feet in depth, with tributaries only slightly less prominent.

The water which falls as rain on Black Mesa is carried southwestward into the Tusayan Washes and the Moenkopi by streams which rise on the most distant rim of the plateau, whereas the run-off received by the Chinle originates on the immediate face of the mountain.

Black Mesa is rather thickly covered by forests of piñon and juniper, with pine on the higher portions and in certain sheltered

[1] Named for Lester F. Ward, whose work in the Painted Desert region marked the beginning of detailed stratigraphic studies for the Navajo Reservation.

A. COAL MINE CANYON, AT NORTH EDGE OF MOENKOPI PLATEAU.

B. EFFECTS OF WIND EROSION, KAIBITO PLATEAU.

C. DUNE AND WIND-SCOURED FLOOR, KAIBITO PLATEAU.

GRAND FALLS, LITTLE COLORADO RIVER.
Photograph by W. C. Mendenhall.

canyons. Sagebrush attains large size and grass of excellent quality is abundant. At Tahchito and elsewhere along the upper valleys Navajos and Hopis practice agriculture, but the principal occupation here, as elsewhere on the reservation, is sheep raising.

Perched high on the southern extremities of Black Mesa are the villages of the Hopis—a singular people of ancient lineage, first made known to the world by Pedro de Tovar and Juan de Padilla of Coronado's expedition in 1540. Sichomovi, Hano, and Walpi, on the "First Mesa," Shipolovi, Mishongnovi, and Shongopovi on the "Second Mesa," Oraibi and Bacobi on the "Third Mesa," and the recently established Hotevila farther north enroll together about 2,000 souls, the remnant of a race whose ruined cliff houses, plains houses, and fields widely distributed over the reservation speak of a large and cultured population. Trading posts, schools, and missions at the Hopi villages and the agency and stores at Keams Canyon bring the whites into contact with this race, which has resisted attempts at civilization ever since the fruitless labors of the early Spanish padres. Corn, melons, and peaches are the crops raised in sand dunes, along washes, and on artificially terraced slopes by a system of agriculture developed through centuries of experiment.

KAIBITO PLATEAU.

North of the Moenkopi Wash, extending to Navajo Canyon, and sharply defined on the west by the line of Echo Cliffs, is an area of geographic unity which may be termed the Kaibito Plateau. Its eastern boundary is in part the escarpment of Black Mesa and in part Red Lake Wash, which trends southward from the rim of Navajo Canyon to join the Moenkopi at Blue Canyon. Its dominating point is White Mesa, a flat-topped, white-walled mass of sandstone, which is notched by picturesque box canyons and attains an elevation of 6,800 feet. Westward from White Mesa, Mormon Ridge, the drainage divide between Navajo and Moenkopi creeks, maintains an elevation of 6,000 to 6,400 feet to its junction with Echo Cliffs. A mesa of equal height stands south of Mormon Ridge, and east of it the igneous needle, Wildcat Peak (Navajo, Nishduitso; 6,648 feet), rises from the plateau surface in such a manner as to be visible for distances of more than 50 miles. The floor of the plateau stands 4,400 feet above sea level at Tuba, and, passing the divide at 6,000 to 6,400 feet, descends to the rim of Navajo Canyon at 5,200 feet and to the Glen Canyon of the Colorado at 4,000 feet. Grass-covered, open valleys supporting sage and piñon mark the northern slopes of the plateau, but the southern slope is under the control of the wind, which has swept bedrock bare and piled dunes high in the lowland (Pl. XI, *B* and *C*). The only permanent streams on Kaibito Plateau are the Moenkopi and the lower stretch of Red Lake Creek, but springs at Kaibito and about White Mesa furnish

supplies for stock, and water is abundant in the Tuba district. Red Lake always holds water, though of poor quality, and sand-bound pools in Begashibito Valley still further increase the supply.

The water of Moenkopi Creek, supplemented by water from springs, furnishes a supply for the most extensive farming carried on within the limits of the Navajo Reservation. In the vicinity of Moenkopi village the ancient cliff dwellers, Hopi Indians, Mormon pioneers, and Government farmers have in turn produced corn, wheat, oats, and fruits beyond their own immediate needs. The oasis of Tuba, settled by the Mormons in 1878 and purchased by the Government for an agency and school site in 1903, has orchards and vineyards, gardens and farms which make this spot, in spite of its desert-like surroundings, the most highly developed section of the reservation. Tuba is accessible from Flagstaff, 90 miles distant, by a road suitable for wagons or automobiles; and from Tuba as a center Lee Ferry, Red Lake, Tyende, or Oraibi may be reached by difficult roads leading across the desert.

PAINTED DESERT.

From Holbrook to the Colorado Canyon the Little Colorado flows through a brightly colored desert valley whose northern side is bounded by the cliffed edge of Ives and Newberry mesas and the walled fronts of Ward Terrace and Kaibito Plateau. This line of cliffs, trenched by Cottonwood, Oraibi, Dinnebito, and Moenkopi washes, and many minor valleys, stands within a mile of the river at Holbrook, below which point it follows the river at a distance of 8 to 10 miles, returning to within 5 miles at Black Point. From Tanner Crossing to Lee Ferry the valley border, continued as Echo Cliffs, again recedes, leaving an irregularly dissected lowland 20 to 25 miles broad. The river itself has developed extensive flood plains between Holbrook and Wolf Crossing and above Grand Falls, and to a less extent between Black Falls and Tanner Crossing. A short canyon below Tolchico and a canyon between Grand and Black Falls confine the stream to narrow limits, and at Tanner Crossing the stream bed is sunk between rock walls which become higher and steeper until a canyon 3,000 feet deep joins the canyon of the Colorado. Low, broken mesas, surrounded by scattered dunes and intricately carved by wind and by water, add relief to the valley floor above Tanner Crossing.

North of Moenkopi Wash, Cedar Mesas and Bodaway Mesa extend westward from Echo Cliffs and form a flat divide separating Roundy Creek,[1] which enters the Colorado, and Hamblin Creek,[2] which fol-

[1] Named for Bishop Roundy, an explorer who lost his life at Lee Ferry in 1876.

[2] Jacob Hamblin, of the Church of the Latter-Day Saints, had charge of the early colonization projects in the Little Colorado Valley. He guided Maj. Powell over the Lee Ferry and Echo Cliffs route in 1871.

lows the base of Echo Cliffs to its junction with the Moenkopi. Overlooking Marble Canyon the remnant of eroded sandstone, known as Shinumo Altar occupies an isolated position, rising 600 feet above the surrounding surface. Lavas, which are abundantly displayed west of Little Colorado River, reach the stream at Grand Falls, Black Falls, Black Point, and at the mouth of Cedar Wash.[1] The lava flow at Grand Falls has produced the picturesque cataract formed at this place (Pl. XII). The only large igneous mass east of the river is Black Knob, a well-known landmark on the lower Little Colorado.

Notwithstanding its large drainage area, the Little Colorado presents a dry bed below Winslow for several months in the year, and whether dry or filled to overflowing, this stream must be crossed with care because of quicksands that have made the river a byword since the days of early exploration. The long stretch from Holbrook to the Colorado was without bridges until 1912, when the Governmen suspension bridge on the Flagstaff-Tuba road put an end to the precarious travel required to reach the western side of the reservation. The Little Colorado Valley is the most arid portion of northern Arizona, and the valley flats and rock slopes between Winslow and the Moenkopi assume the character of a true desert with restricted and specialized plant and animal life. Water is alkaline or is lacking except immediately along the stream, and the Navajo side of the river is accordingly not populated. The only compensation for bare rock and gravel floor, intense heat, sand storms, and lack of vegetation is the magnificent coloring of cliffs and floor which justifies the name Painted Desert.[2] The superintendents of the Western Navajo and the Navajo Extension reservations have joint charge of the few Indians who use the Little Colorado Valley as a grazing ground. Schools at Leupp and at Tuba and the mission stations at Lyons ranch, Moenkopi, and Tolchico enlarge the sphere of influence exercised by the white man.

SHATO PLATEAU.

The long Klethla Valley, extending westward from Marsh Pass, forms the southern margin of a group of canyons and mesas which extends northward to the head of Piute Canyon and westward to Red Lake Valley and the south branch of Navajo Canyon. Near the center of this area is the well-known spring Shato (Navajo, the mirror), whose name is here applied to the plateau on which

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[1] Gregory, H. E., A reconnaissance of a portion of the Little Colorado Valley, Ariz.: Am. Jour. Sci., 4th ser., vol. 38, pp. 491–501, 1914.

[2] This term was applied by Ives and Newberry to the east side of the Little Colorado Valley between Sunset Crossing (Winslow) and Tanner Crossing, and the geologic formation name "Painted Desert" was used by Ward (U. S. Geol. Survey Mon. 48) for strata in this same area. It is here proposed to extend the term to include the region of identical character between the Moenkopi Wash and the Colorado. The use of Painted Desert as a geographic term in portions of the Puerco Valley is not justified.

this spring is found. This region has an average elevation of 7,000 feet, reaching 6,000 feet at its southwestern edge and 7,800 feet on its northern border. The Shato Plateau forms the water parting for streams flowing northward into the San Juan, westward into the Colorado, southwestward via Red Lake and the Moenkopi into the Little Colorado, and eastward through Tyende and Chinle creeks into the San Juan. It thus becomes the four-sided roof of the reservation. The surface of the plateau is marked by wide, flat-floored valleys with intervening poorly dissected mesas. At its edges deeply cut, box-headed canyons project into the area from all sides. Spring-fed streams start at nearly all the canyon heads and continue with more or less interrupted flow until their master streams are reached. The valleys trending south, particularly Shato and Begashibito, present the abnormal feature of a string of lakes and pools separated by drifts of sand. Other pools and tanks occur in the washes near the divide. The plateau therefore is provided with sufficient water to enable the Indians to utilize the forage which is fairly plentiful among the sage and piñon. No white men inhabit Shato Plateau and no feasible road traverses it. Ruined buildings and abandoned fields of an ancient people are to be found along the watercourses, and within the National Monument on Keet Seel is included one of the best-preserved cliff villages so far described.[1]

RAINBOW PLATEAU.

The most inaccessible, least known, and roughest portion of the Navajo Reservation is bounded by the Navajo, Colorado, San Juan, and Piute canyons. The region is essentially an area of bare red rock forming narrow divides between innumerable canyons 200 to 2,000 feet deep, which lead directly or by way of Navajo, Piute, and San Juan canyons into Colorado River. The plateau is carved with incredible intricacy and presents a picture very inadequately represented on the Echo Cliffs, Marsh Pass, Henry Mountains, and Escalante topographic maps of the Geological Survey. Flat-topped mesas, standing at 6,000 feet in the vicinity of Tower Butte, between Navajo Canyon and the Utah line, mark the old surface into which the canyons have been sunk, and above the plateau surface rises the solitary dome of Navajo Mountain to a height of 4,000 feet—10,416 feet above sea level. The canyons cut in the red sandstone of the La Plata group are 600 to 1,000 feet deep and are so closely spaced that interstream mesas are but slightly developed. Buttes, mesas, and small domes predominate and are so tightly packed that the base of one flattened dome of erosion butts against that of its neighbor. The deep canyon trenches are practically impassable and the

[1] Fewkes, J. W., Preliminary report on a visit to the Navajo National Monument, Ariz.: Bur. Am. Ethnology Bull. 50, 1911.

buttresses flanking the cathedral spires are so narrow, smooth, and rounded that passage from one to another and access to the capping mesas have so far not been attained. Whether the ancient cliff dwellers made use of these mesa tops is yet undetermined.

The bare red rock walls of many of the canyons are beautifully carved. Among the features represented are natural bridges, one of which spans Bridge Canyon (Navajo, Nonnezoshiboko, great arch) as a symmetrical arch of red sandstone and has received the Piute name of Barohoini, the Rainbow.[1] The bridge has a span of 274 feet and rises 308 feet above the canyon floor (Pl. XIII, *A*).

Water is plentiful in the streams flowing north from Navajo Mountain and springs occur at long intervals about the mountain's base. Water may be found also in Piute and Navajo canyons and about the ancient ruins between the heads of these canyons. Elsewhere water, when present, is hidden away in almost inaccessible spots, and the experience of my party indicates that exploration in this canyoned land may be accompanied by hardships. Probably 40 per cent of the Rainbow Plateau is practically without vegetation, but between the ledges grass grows luxuriantly, except near the springs at the southwest base of the mountain. Scattering piñons find room on mesa and canyon walls, and a variety of shrubs are found along the floor of the deep canyons.

NAVAJO MOUNTAIN.

Navajo Mountain is the commanding feature of Rainbow Plateau.[2] Under the name "Sierra Panoche" this eminence is indicated on the Macomb-Newberry map of 1859. These explorers saw the mountain from a distance of 75 miles at a point between Monticello and Bluff. Dutton describes the setting of Navajo Mountain as seen from the Utah plateaus:

> Far to the southeastward, upon the horizon, rises a gigantic dome of wonderfully symmetric and simple form. It is the Navajo Mountain. Conceive a segment of a sphere cut off by a plane through the seventieth parallel of latitude and you have its form exactly. From whatsoever quarter it is viewed, it always presents the same profile. It is quite solitary, without even a foothill for society, and its very loneliness is impressive.[3]

At nearer approach the sides are seen to be cut into vertical canyons and deep gorges by drainage lines. In places, particularly on the

[1] The existence of this bridge was reported to me in July, 1909, by John Wetherill, who received his information from a Piute herdsman. A visit to this locality during this year was prevented by other obligations. In August, 1909, Mr. W. B. Douglass, of the General Land Office, in company with Prof. Byron Cummings, of the University of Utah, were conducted to the bridge by Wetherill and Colville, of Oljeto. So far as known the Rainbow had not been viewed by white men before that date. This bridge has been described by my assistant, Joseph E. Pogue (The great Rainbow Natural Bridge: Nat. Geog. Mag., vol. 22, pp. 1048–1056, 1911).

[2] The topographic map of Navajo Mountain gives a very imperfect representation of its contour.

[3] Dutton, C. E., Geology of the high plateaus of Utah: U. S. Geog. and Geol. Survey Rocky Mtn. Region, pp. 290–291, 1880.

southeast, the outline is subdued because of the presence of enormous deposits of material in the form of fans, alluvial slopes, and rock streams. The less eroded parts of the top of the mountain present a plateau with flaring edges which are scalloped by canyon walls. The short canyons, with steep gradients, leading northward and northwestward removed about equal amounts of material, so that these sides of the mountain present a sloping plain. A stream leading southwest has cut far into the heart of the mass, so that the top presents the outlines of a gigantic horseshoe. The higher parts of the mountain consist of low ridges, imperfectly drained flats, small cliffs, and miniature canyons cut in quartzite, and this material has been so broken along joint planes by frost that areas acres in extent are covered with piles of angular blocks so large as to practically prohibit travel over them. The slopes of the minor ridges are strewn with bowlders, and in three localities these fragments of quartzite are arranged as rock flows, extending down the slope for 200 to 300 feet and forming at the base ridges with much the appearance of glacial moraines.

In addition to being the highest point on the reservation, the position of Navajo Mountain on the very edge of the Glen Canyon of the Colorado (3,400 feet above sea) gives its summit the advantage of a wider viewpoint than that afforded by any other height on the Colorado Plateau. The grandeur and beauty of the erosive work of streams can nowhere be better observed. The panorama observed from the top of the mountain leaves a lasting impression on the mind. From selected spots an uninterrupted sweep of vision may be had of all points of the compass. Lookout Ridge, extending westward from the mountain summit, is particularly well placed for comprehensive views. Toward the northeast the highland surmounted by the beautiful dome of Abajo is plainly visible at a distance of 80 miles; on the north the Henry Mountains dominate the landscape, and a little to the west the great cliff-bordered table of the Aquarius Plateau stands outlined against the higher plateau districts of central Utah. Nearer at hand in the same direction is the little-known Kaiparowitz Plateau, and in still nearer view the canyons of San Juan and Colorado rivers are so clearly outlined that sand bars and patches of vegetation are distinctly visible from this distance. To the west are seen the Vermilion Cliffs, the tangle of canyons at the junction of the Little Colorado with its master stream, and the blue sky line of the Coconino and Kaibab plateaus. Still farther toward the southwest San Francisco Mountain stands high above its plateau floor and justifies its position in Navajo myths as one of the supports on which the vault of heaven rests. To the south and southeast the Black Mesa forms the horizon, while nearer at hand Segi Mesas and the labyrinth of canyons tribu-

A. RAINBOW BRIDGE, BRIDGE CANYON.

B. VEGETATION AT NASJA (OWL) BRIDGE, ON THE NORTH SLOPE OF NAVAJO MOUNTAIN.

A. COMB MONOCLINE EAST OF MARSH PASS.

B. KEET SEEL CLIFF RUIN, IN BRANCH OF LAGUNA CANYON.

tary to the Piute and Navajo cut the surface into tables, ridges, and minute domes of painted rock.

In marked contrast to the Rainbow Plateau, Navajo Mountain is covered with vegetation. Above an elevation of 7,000 feet there is an open stand of yellow pine, with trees ranging in diameter from 6 inches to 2 feet, averaging perhaps 10 inches, and attaining a height or 50 or 60 feet. Piñon and juniper form a belt surrounding the mountain at an elevation below 7,000 feet. The yellow pine covers the mountain, in general, and is particularly well developed on the eastward and northward facing slopes and in open swales below 9,000 feet. This forest could furnish a timber supply if needed, but there is no likelihood that it will ever be made of use. Red fir is found in a few localities, and Rocky Mountain fir was noted on some of the higher slopes. Aspen is fairly abundant in side valleys and rock slopes, and trees of this species 1 inch to 10 inches in diameter occur even on the extreme top. Willows are found in the wetter valley basins. Wild roses, manzanita, a primrose of unusual beauty, flax, the Indian paintbrush, sage, and clematis indicate that this is but an island in the sea of vegetation characteristic of the Southwest, and the ground juniper gives a suggestion of the flora of New England. (See Pl. XIII, *B*.)

War God Spring, on a bench facing the southeast at an elevation of 8,600 feet, is an excellent water supply. Its source is in deep talus at the head of a broad, flat valley. The water is clear, has a temperature of 47°, and flows in sufficient abundance to supply a small stream, which, however, continues but a short distance down the mountain flank. The spring with its small stream furnishes an ideal camping spot.

In 1910 our party had the pleasure of making the first geologic study of Navajo Mountain, a project not heartily approved by the Indians. To the Navajo the mountain has sacred associations, and the presence in this vicinity of a few renegade Piutes still further tends to discourage settlement.[1] No Indians were seen about Navajo Mountain in either 1910 or 1913, and it is probable that less than 100 Indians make their home on Rainbow Plateau.

SEGI MESAS.

The highland between Piute and Laguna (upper Tyende) canyons on the west and Monument Valley on the east reaches its highest point in Skeleton Mesa (7,790 feet). The summit mesa is flanked on the east by Tyende, Azansosi, and Hoskininni mesas, lying 1,000 feet below the upper level. These mesas in turn lie 1,000 feet above the floor of upper Moonlight Valley (Navajo, Oljeto). The east face of Segi Mesas thus presents the appearance of a stairway of two wide treads separated by two risers 1,000 feet in height. The

[1] The Navajo term for the mountain is Na-dis-an, "the enemies' hiding place."

whole region is a series of mesas piled on mesas, surrounded and intersected by chasms attaining maximum depths exceeding 1,200 feet. Both the north and south ends of the long, narrow mesas are penetrated by canyons, and the streams flowing eastward have cut far back, leaving but fragments of the tables in place. Between the heads of Tyende and Piute creeks the surface is marked by shallow wide-floored canyons, above which rise Zilnez and similar erosion remnants, whose preservation is due to resistant strata of limestone.

A perennial stream occupies Laguna, Copper, and Nokai canyons, and living water, fed by springs, flows for short distances in many other channels. At the time the topographic map was made (1883), Laguna Canyon held a number of lakes which have disappeared in consequence of recent deep trenching of the alluvial fill. The canyons of Segi Mesas were the home of the most populous center of cliff dwellers to be found on the Navajo Reservation (Pl. XIV, *B*). Many of the houses are in an excellent state of preservation, and few of them have been studied by archeologists.[1] The descendants of the cliff dwellers no longer occupy this country. In their place are groups of Navajos who use the excellent forage of the mesas to support thousands of sheep. The Segi Mesas may be reached readily from Tyende, and offer an attractive field for geographic and archeologic research.

MONUMENT VALLEY.

Monument Valley is triangular in shape. Its north boundary is San Juan River, and its west, Segi Mesas. The triangle is closed by Comb Ridge, a remarkable wall formed of the upturned edges of strata extending in a curved line from Marsh Pass to the mouth of the Chinle (Pl. XIV, *A*). The floor of the valley is a dome rising gradually from 4,800 feet in Gypsum Valley to 5,200 feet at the Monuments, then again descending, toward the west, to 4,800 feet in the upper Moonlight Valley, following the dip of the strata. On the valley floor rest mesas and buttes ranging from spires to flat-topped masses several square miles in area. The most conspicuous erosion features are the "monuments," which rise nearly 1,000 feet above the crest of the dome (Pl. XV, *A*). Igneous masses also dot the surface and find their best expression in Agathla, a spire which rises 1,225 feet above the plain at its base—the most impressive of all volcanic necks within the Navajo country (Pl. XV, *B*).

Monument Valley is well supplied with grass, but poorly supplied with water suitably located for sheep raising. As a cattle country, however, it has no superior within the limits of the reservation. The water from Segihatsosi and Moonlight, from the Tyende, and from the few springs is highly satisfactory, but the water in the chief

[1] For a description of three large cliff ruins of this region, and for a map showing the correct location of canyons tributary to Laguna, see Fewkes, J. W., Navajo National Monument, Ariz.: Bur. Am. Ethnology Bull. 50, 1911.

A. MITTEN BUTTE, MONUMENT VALLEY.

Height approximately 800 feet.

B. AGATHLA, A VOLCANIC NECK, MONUMENT VALLEY.

Height above base, 1,225 feet.

stream of the valley, Gypsum Creek, is unpalatable for man or beast. No white settlements exist within Monument Valley, but stores and the Government station at Tyende and the trading posts at Mexican Water and Round Rock are within reach of the few Navajos and Piutes, who make this valley their home.

CLIMATE.

GENERAL CONDITIONS.

As the Navajo Reservation is outside the usual path of cyclonic storms the procession of high and low barometer, warm and cold "spells," and wet and dry periods which characterizes the climate of most other parts of the United States is absent. There is a difference of about 2° 21′ of latitude between the southern and the northern edges of the area, but the influence of this factor is so completely nullified by topography that Hite, 40 miles north of the reservation line, in latitude 37° 50′, is warmer and dryer than Holbrook, in latitude 34° 55′. Topography, in fact, may be considered the primary factor in the climate of the Navajo country. Fort Defiance, elevation 6,900± feet, is colder and wetter than Holbrook, Tuba, and Aneth, at an elevation 2,000 feet lower. In the Little Colorado Valley group of meteorologic stations, Flagstaff, elevation 6,907 feet, has a rainfall of 23.87 inches and a mean annual temperature of 44.7°; Holbrook, elevation 5,069 feet, has 9.16 inches of rain and a mean annual temperature of 54.2°; and Winslow, elevation 4,853 feet, follows with an annual rainfall of about 7 inches and a mean annual temperature of over 55°.

A snowfall of 2 inches per year is normal for Holbrook, elevation 5,069 feet; the corresponding figure for St. Michaels, elevation 6,900 feet, is 46.1 inches. At elevations on the reservation above 7,000 feet snow may fall at any time between October 1 and June 1, and may remain on the ground for days or even weeks. My Indian guide states that in some years snow lies on Navajo Mountain, 10,416 feet, well into July, and San Francisco Mountain, 12,611 feet, retains its snow in protected places throughout the year. The general effect of elevation is greatly modified by secondary topographic features. The climate of the floor of a canyon may be quite unlike that of the canyon rim, and the cliff dwellers long ago learned that one canyon wall offers favorable home sites not afforded by the opposite wall.

Clear skies prevail in this region. Flagstaff, 40 miles west of the reservation line, receives 81 per cent of the possible sunshine, and it has been estimated by the United States Weather Bureau that northern Arizona as a whole has, on the average, 210 clear days, 85 partly cloudy, and 70 cloudy days in the year. During May, June, October, and November the skies may be cloudless for 5 to 15 days in succession. In the sun the heat of summer is intense; in the shade of a rock or tree coolness prevails; and, unlike humid regions, the line

between scorching heat and delightful temperatures is sharply drawn at the edge of a shadow.

The topography is so varied that in the absence of cyclonic storms the region may be said to have a group of local climates of widely dissimilar aspect. The daily range of temperature is over 40°, and usually exceeds the difference between the means of the warmest and of the coldest months in the year, and, consequently, cool or even uncomfortably cold nights follow the heated day.

In general, the keynote of the climate of the Navajo country is variability. Canyon adjoining plateau, two adjoining valleys, the opposite sides of mountains and mesas, and even opposing canyon walls may have different climates. The summers are very hot; the winters are very cold; daylight is accompanied by heat; darkness by chilliness. The annual, seasonal, monthly, and daily rainfall is subject to wide variations. During July and August rain falls in quantities sufficient to flood the country; in other months precipitation is deficient.

PRECIPITATION.

RECORDS.

Miscellaneous observations on rainfall for the Navajo country are contained in the reports of the earlier scientific explorers and the records of the War Department. After the army post was established at Fort Defiance, in 1852, rainfall was measured for eight years (1853–1860). At this place or at St. Michaels complete records are available for the 16-year period 1898 to 1913. If Fort Defiance and St. Michaels are treated as one station, they furnish a longer continuous record than any other station in the Navajo country. At Holbrook the precipitation was recorded for 19 years, including one period of 12 consecutive years (1888 to 1899). The records for Keams Canyon include 5 complete years, of which 4 are consecutive; those for Winslow include 4 complete and 2 consecutive years; Tuba, 7 complete, 5 consecutive years; Fruitland, 5 complete, 2 consecutive years; Aneth, 5 complete, 3 consecutive years; and Hite, 9 complete, 4 consecutive years. These records are too fragmentary for general climatic studies; they suffice, however, to indicate the quality of the rainfall. Care has therefore been taken to obtain from published and unpublished documents significant material relating to precipitation in this area. It should be remembered that all observations have been made by voluntary observers, without whose unselfish services a discussion of the climate of northern Arizona and southern Utah would be wholly speculative. These records enable those interested in water development and agriculture to plan intelligently, for they indicate in a general way the total precipitation, its distribution with reference to the growing season for crops, and whether showers of brief duration or long-continued "soaking" rains normally occur.

Records of precipitation in the Navajo country.

Fort Defiance and St. Michaels, Ariz.

[On the edge of Defiance Plateau. Elevation, 6,900± feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1853	......	......	......	......	......	......	......	......	......	......	......	......	13.87
1854	......	......	......	......	......	......	......	......	......	......	......	......	22.44
1855	......	......	......	......	......	......	......	......	......	......	......	......	17.07
1856	......	......	......	......	......	......	......	......	......	......	......	......	11.63
1857	......	......	......	......	......	......	......	......	......	......	......	......	13.06
1858	......	......	......	......	......	......	......	......	......	......	......	......	11.97
1859	......	......	......	......	......	......	......	......	......	......	......	......	11.44
1860	......	......	......	......	......	......	......	......	......	......	......	......	11.84
1881	0.98	0.70	0.84	0.67	0.52	2.44	0.00	2.73	1.86	0.70	1.16	0.87	14.21
1897	......	......	......	......	......	......	1.42	1.36	3.06	1.53	.46	1.15	......
1898	2.00	.25	1.04	.31	.28	.75	1.97	2.53	.16	.00	1.10	1.40	11.78
1899	.80	2.20	.25	Tr.	.02	.37	4.03	1.73	.78	1.05	.60	.80	12.63
1900	Tr.	Tr.	.80	1.36	.17	.20	.20	.62	1.82	.65	.70	Tr.	6.52
1901	1.40	2.40	.17	.90	3.38	.02	2.24	.99	.35	.65	.40	.43	13.33
1902	1.31	.65	1.03	.30	1.50	.70	.22	2.81	1.00	.50	1.80	1.05	12.87
1903	.42	2.47	1.85	.85	1.14	4.67	.55	4.03	2.51	.00	.00	.02	18.51
1904	.00	.42	.75	.05	1.90	.55	2.51	3.34	.55	.20	.00	.87	11.14
1905	2.20	3.62	1.76	2.61	.20	.70	1.11	.98	2.55	.13	3.58	1.21	20.65
1906	.13	1.13	1.41	.33	.17	.00	1.13	2.08	1.70	.45	1.37	1.93	11.83
1907	.89	.79	1.13	.74	.34	.34	1.92	3.70	.56	2.10	.56	.60	13.67
1908	.50	1.59	.66	.86	.53	.15	.79	2.96	1.18	.39	.74	1.80	12.15
1909	.60	.68	.61	.31	.08	Tr.	2.46	5.75	1.87	.09	.48	1.66	14.59
1910	.74	.13	.50	.38	.05	.76	3.01	1.04	.67	1.13	.84	1.26	10.51
1911	1.87	2.36	1.91	.74	Tr.	.70	4.17	1.35	1.88	2.65	Tr.	.65	18.28
1912	Tr.	.10	1.77	.55	Tr.	.96	1.33	1.11	Tr.	2.03	Tr.	.05	7.90
1913	.08	5.81	.94	.37	Tr.	Tr.	.95	3.18	3.50	1.25	1.55	1.74	19.37
Mean	.82	1.49	1.02	.66	.60	.78	1.11	2.22	1.48	.86	.85	.91	12.80

Period.	Mean.	Total amount for driest year.	Total amount for wettest year.	Mean snowfall.
December	0.91	Tr.	1.21	5.4
January	.82	Tr.	2.20	6.3
February	1.49	Tr.	3.62	5.6
Winter mean	3.22	Tr.	7.03	17.3
March	1.02	0.80	1.76	3.6
April	.66	1.36	2.61	2.3
May	.60	.17	.20	....
Spring mean	2.28	2.33	4.57	5.9
June	.78	.20	.70	....
July	1.11	.20	1.11	....
August	2.22	.62	.98	....
Summer mean	4.11	1.02	2.79	....
September	1.48	1.82	2.55	....
October	.86	.65	.13	1.2
November	.85	.70	3.58	2.2
Fall mean	3.19	3.17	6.26	3.4
Annual mean	12.80	6.52	20.65	26.6

NOTE.—The records for the years 1853 to 1905 are for Fort Defiance. In 1905 the station was removed to St. Michaels. The two places are 8 miles apart and are closely similar in topographic environment.

Records of precipitation in the Navajo country—Continued.

Winslow, Ariz.

[On a terrace about 50 feet above the bed of Little Colorado River. Elevation, 4,853 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1892	......	1.20	0.75	Tr.	0.40	0.20	0.80	......	Tr.	0.55	0.10	......	......
1898	......	......	......	......	......	......	......	......	......	......	......	0.85	......
1899	1.07	.30	Tr.	.00	Tr.	.75	Tr	1.07	0.10	.98	.18	Tr.	4.45
1900	.06	.44	.40	.84	.53	.08	.20	1.73	.46	.89	.20	Tr.	5.83
1908	......	......	......	......	......	......	......	......	......	1.18	.15	4.38	......
1909	1.48	.85	.49	.13	.02	Tr.	1.75	2.79	.22	.00	.75	1.74	10.22
1910	1.66	.40	.40	.20	Tr.	.41	.60	2.52	.13	.03	.86	.20	7.41
1911	.84	1.35	1.33	.36	.00	......	......	1.28	2.41	......	......	.20	......
1912	.00	.00	1.30	.70	.00	......	......	......	......	......	......	......	......
1913	.00	......	.03	......	......	......	......	......	......	......	......	......	......
Mean	.73	.57	.59	.32	.13	.36	.67	1.34	.47	.52	.32	1.05	7.07

Period.	Mean.	Total amount for driest year.	Total amount for wettest year.	Mean snowfall.
December	1.05	Tr.	1.74	....
January	.73	1.07	1.48	....
February	.57	.30	.85	....
Winter mean	2.35	1.37	4.07	....
March	.59	Tr.	.49	....
April	.32	.00	.13	....
May	.13	Tr.	.02	....
Spring mean	1.04	.00	.64	....
June	.36	.75	Tr.	....
July	.67	Tr.	1.75	....
August	1.34	1.07	2.79	....
Summer mean	2.37	1.82	4.54	....
September	.47	.10	.22	....
October	.52	.98	.00	....
November	.32	.18	.75	....
Fall mean	1.31	1.26	.97	....
Annual mean	7.07	4.45	10.22	....

Records of precipitation in the Navajo country—Continued.

Tuba, Ariz.

[On the edge of Kaibito Plateau overlooking the Little Colorado Valley. Elevation, about 4,700 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	......	......	......	0.09	0.26	Tr.	0.19	0.25	1.34	1.73	0.55	0.25	......
1898	0.78	0.12	Tr.	......	.75	......	......	......	......	......	.06	.58	......
1899	.04	.02	.20	.50	.00	.49	Tr.	.87	.00	.25	.26	Tr.	8.38
1900	.15	Tr.	.60	......	......	......	......	......	......	1.46	Tr.	.00	......
1901	.83	.73	.20	......	Tr.	Tr.	.45	.09	.00	.30	Tr.	.00	......
1902	.10	Tr.	.45	.00	.15	Tr.	.37	.67	.08	......	.97	.15	......
1903	.00	.20	.44	.38	Tr.	.75	.60	......	......	......	......	......	......
1904	......	......	.16	.00	.15	.11	.96	1.59	.20	.30	.00	......	......
1905	1.45	1.21	.96	2.58	......	......	......	......	......	......	2.32	.90	......
1906	.53	.34	1.59	.19	.34	.00	1.73	1.26	1.37	.07	2.92	2.23	12.57
1907	2.00	.38	.23	......	......	......	......	......	......	......	......	.42	......
1908	.40	1.61	......	.63	.16	.32	.35	1.24	.27	.30	.37	1.77	......
1909	.62	.72	.37	.41	.20	Tr.	.54	1.66	.56	1.10	.30	1.54	8.32
1910	.25	.53	.44	.42	.05	.75	.89	.34	.16	.15	1.23	.39	5.60
1911	.87	1.14	.92	.05	.00	.39	1.90	.37	1.98	1.46	Tr.	.05	8.33
1912	Tr.	Tr.	1.43	.86	.02	.15	.98	.35	.03	1.84	.01	.82	6.49
1913	.34	2.03	.31	.12	Tr.	.17	.58	.49	.62	.66	.85	.42	6.69
Mean	.49	.52	.48	.37	.11	.18	.56	.54	.35	.56	.58	.56	5.30

Period.	Mean.	Total amount for driest year.	Total amount for wettest year.	Mean snowfall.
December	0.56	0.39	2.23	10.0
January	.49	.25	.53	....
February	.52	.53	.34	6.2
Winter mean	1.57	1.17	3.10	16.2
March	.48	.44	1.59	....
April	.37	.42	.19	....
May	.11	.05	.34	....
Spring mean	.96	.91	2.12	....
June	.18	.75	.00	....
July	.56	.89	1.73	....
August	.54	.34	1.26	....
Summer mean	1.28	1.98	2.99	....
September	.35	.16	1.37	....
October	.56	.15	.07	....
November	.58	1.23	2.92	....
Fall mean	1.49	1.54	4.36	....
Annual mean	5.30	5.60	12.57	16.2

Records of precipitation in the Navajo country—Continued.

Chinle, Ariz.

[At the east side of Chinle Valley at the base of Defiance Plateau. Elevation, about 5,200 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1909	0.14	0.25	0.68	0.20	0.01	Tr.	2.14	3.67	1.63	0.00	0.47	1.43	11.62
1911	.48	1.44	1.44	.19	.01	.97	3.59	1.40	2.80	1.23	.05	3.96	17.56
1912	.03	Tr.	.94	.65	.03	.71	1.02	1.77	.14	1.16	.26	.12	5.83
1913	.15	.74	......	.89	.02	.26	1.28	.51	1.13	1.56	.81	.45	7.80
Mean	.20	.60	.76	.48	.01	.48	2.00	1.83	1.42	.96	.39	1.49	10.62

Period.	Mean.	Total amount for driest year.	Total amount for wettest year.	Mean snowfall.
December	1.49	0.12	3.96	4.9
January	.20	.03	.48	2.0
February	.60	Tr.	1.44	2.9
Winter mean	2.29	.15	5.88	9.8
March	.76	.14	1.44	.8
April	.48	.65	.19	1.5
May	.01	.03	.01	Tr.
Spring mean	1.25	.62	1.64	2.3
June	.48	.11	.97	.0
July	2.00	1.02	3.59	.0
August	1.83	1.77	1.40	.0
Summer mean	4.31	3.50	5.96	.0
September	1.42	.14	2.80	.0
October	.96	1.16	1.23	.0
November	.39	.26	.05	1.7
Fall mean	2.77	.56	4.08	1.7
Annual mean	10.62	5.83	17.56	13.8

Records of precipitation in the Navajo country—Continued.

Fruitland, N. Mex.

[On the flood plain of San Juan River. Elevation, about 5,200 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1903	0.09	0.75	0.10	......	0.03	......	0.09	......	......	0.00	0.00	Tr.	....
1904	.12	Tr.	.07	Tr.	1.10	Tr.	.03	0.06	0.53	1.16	.00	0.26	3.33
1905	.56	1.15	.64	2.39	Tr.	0.95	1.26	.09	.23	Tr.	1.75	.15	9.17
1906	Tr.	.30	1.91	1.43	.06	.00	1.05	......	1.47	.13	1.18	1.31	....
1907	.12	.22	.14	......	.55	.52	1.52	2.26	.20	1.30	.20	.44	....
1908	.32	1.57	.01	.37	.36	Tr.	1.44	1.06	Tr.	.03	Tr.	.85	6.01
1909	.31	.42	.57	......	Tr.	Tr.	.31	2.25	.95	.02	.05	.94	....
1910	.29	.22	.05	1.04	.00	.25	.90	.48	.42	1.45	.67	.32	6.09
1911	.48	1.44	.69	.50	Tr.	.37	4.50	.30	2.88	1.50	.25	.17	13.08
1912	.00	.13	1.07	.52	Tr.	.32	2.29	.60	.01	......	Tr.	.12	....
1913	Tr.	.87	......	Tr.	.00	Tr.	1.57	.51	1.42	1.87	1.87	1.20	....
Mean	.22	.63	.47	.67	.19	.21	1.34	.69	.73	.67	.54	.53	6.89

Period.	Mean.	Total amount for driest year.	Total amount for wettest year.	Mean snowfall.
December	0.53	0.26	0.17	5.20
January	.22	.12	.48	1.10
February	.63	Tr.	1.44	1.00
Winter mean	1.38	.38	2.09	7.30
March	.47	.07	.69	1.00
April	.67	Tr.	.50	2.00
May	.19	1.10	Tr.	.15
Spring mean	1.33	1.17	1.19	3.15
June	.21	Tr.	.37	....
July	1.34	.03	4.50	....
August	.69	.06	.30	....
Summer mean	2.24	.09	5.17	....
September	.73	.53	2.88	....
October	.67	1.16	1.50	....
November	.54	.00	.25	.20
Fall mean	1.94	1.69	4.63	.20
Annual mean	6.89	3.33	13.08	10.65

Records of precipitation in the Navajo country—Continued.

Aneth, Utah.

[On a terrace overlooking San Juan River. Elevation, about 4,700 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1901	1.06	0.86	0.33	0.18	0.30	0.51	1.05	1.46	0.00	0.36	0.00	0.01	6.12
1902	.06	.19	.46	.01	.37	.00	.19	1.22	.35	.00	1.36	1.09	5.30
1903	.11	.50	1.54	.59	.12	.51	.38	.04	.93	.06	.00	.02	4.80
1904	.05	.07	.10	.03	.62	Tr.	......	......	......	.50	.00	.28	......
1905	1.67	1.71	1.02	1.40	.39	Tr.	.37	.07	1.95	.00	1.96	.20	10.74
1906	.29	Tr.	1.06	.55	.25	.00	1.20	.54	......	.11	1.01	1.08	......
1907	.85	.41	.72	.52	.85	.54	.49	2.39	.35	......	......	......	......
1911	.51	.83	.85	......	.00	.29	2.40	.71	......	2.48	.12	.16	......
1912	.09	.05	1.57	.28	.04	.02	.56	.30	.00	.97	.02	.10	4.00
1913	.25	1.12	.68	.10	.20	.00	1.02	......	......	......	......	......	......
Mean	.49	.58	.83	.26	.31	.18	.15	.66	.35	.44	.44	.27	4.96

Period.	Mean.	Total amount for driest year.	Total amount for wettest year.	Mean snowfall.
December	0.27	0.10	0.20	....
January	.49	.09	1.67	....
February	.58	.05	1.71	....
Winter mean	1.34	.24	3.58	....
March	.83	1.57	1.02	....
April	.26	.28	1.40	....
May	.31	.04	.39	....
Spring mean	1.40	1.89	2.81	....
June	.18	.02	Tr.	....
July	.15	.56	.37	....
August	.66	.30	.07	....
Summer mean	.99	.88	.44	....
September	.35	.00	1.95	....
October	.44	.97	.00	....
November	.44	.02	1.96	....
Fall mean	1.23	.99	3.91	....
Annual mean	4.96	4.00	10.74	....

Records of precipitation in the Navajo country—Continued.

Hite, Utah.

[In the canyon of Colorado River at the mouth of Trachyte Creek. Elevation, about 3,500 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1902	......	0.60	......	......	0.40	0.00	0.09	0.87	0.65	Tr.	1.29	0.20	....
1903	0.30	.24	0.64	0.26	.23	.50	.63	Tr.	.32	Tr.	.00	.00	3.12
1904	.10	.60	.45	Tr.	.84	.08	.15	1.06	.55	0.36	.00	.25	4.44
1905	.76	1.52	1.31	.98	1.58	Tr.	.45	.19	1.59	.15	3.83	Tr.	12.36
1906	.74	.22	1.42	.39	.45	Tr.	.45	1.28	1.84	.11	......	.76	....
1907	.53	.45	.51	.82	1.41	.48	1.21	1.31	.21	.62	.45	.30	8.30
1908	.31	1.43	.84	.20	.28	.14	1.06	1.14	.63	1.29	.18	1.83	9.33
1909	1.27	.84	.43	.63	.06	.00	.36	1.05	1.70	Tr.	.10	2.27	3.71
1910	.97	.21	.87	.12	Tr.	.77	Tr.	.58	.22	.67	.85	.74	6.00
1911	......	.78	.53	.35	.00	1.22	.04	.20	1.12	2.92	.15	.68	....
1912	.08	.34	2.28	.44	.12	.03	.47	.14	.08	2.25	.14	.48	6.85
1913	.31	.81	.28	.14	Tr.	.05	.44	.50	.62	.58	.66	.77	5.16
Mean	.48	.67	.87	.39	.45	.27	.38	.61	.73	.74	.64	.69	6.92

Period.	Mean.	Total amount for driest year.	Total amount for wettest year.	Mean snowfall.
December	0.69	0.00	Tr.	....
January	.48	.30	0.76	....
February	.67	.14	1.52	....
Winter mean	1.84	.54	2.28	....
March	.87	.64	1.31	....
April	.39	.26	.98	....
May	.45	.23	1.58	....
Spring mean	1.71	1.13	3.87	....
June	.27	.50	Tr.	....
July	.38	.63	.45	....
August	.61	Tr.	.19	....
Summer mean	1.26	1.13	.64	....
September	.73	.32	1.59	....
October	.74	Tr.	.15	....
November	.64	.00	3.83	....
Fall mean	2.11	.32	5.57	....
Annual mean	6.92	3.12	12.36	....

GEOGRAPHIC DISTRIBUTION.

The influence of geographic position on distribution of rainfall is apparent on comparison of records of the various stations. In the valley of the Little Colorado rainfall is low; at Holbrook, Winslow, and Tuba, with altitudes of 5,069, 4,853, and 4,700 feet, the mean annual rainfall is 9.15, 7.07, and 5.30 inches, respectively. At stations in the center of the reservation precipitation is heavier than the normal for the Little Colorado Valley. The records for Fort Defiance-St. Michaels (6,900 feet), Chinle (6,600 feet), and Keams Canyon (5,200 feet), on the southern edge of Black Mesa, show, respectively, 12.80, 10.62, and 10.94 inches. San Juan Valley resembles Little Colorado Valley in amount and distribution of rainfall. Fruitland, 5,200 feet above sea level, receives 6.89 inches of rain; at Aneth, 60

miles farther down the stream and 500 feet lower, the record shows 4.96 inches. The stations at Holbrook, Winslow, Tuba, Aneth, and Fruitland are in the plant zone of cottonwood and yucca. Chinle, Keams Canyon, and Fort Defiance are in the piñon zone, Fort Defiance being on the immediate border of the zone of yellow pine. It is probable that stations on Defiance Plateau, Black Mesa, and in the Chuska Mountains would record about 15 inches of rain, and the vegetation of Navajo Mountain suggests a rainfall exceeding 20 inches. On the other hand, the precipitation along the lower course of the Little Colorado probably does not exceed 3 inches a year.

VARIATION FROM YEAR TO YEAR.

The variation in amount of rainfall from year to year ranges between half the normal and twice the normal, measured through a period of years (fig. 2). For Fort Defiance the wettest year on record is 1854, when 22.44 inches of rain was measured. In the last 10 years at this station 3 years—1905, 1911, and 1913—have been wet, the heaviest fall coming in 1905, when the precipitation (20.65 inches) exceeded the normal by more than 60 per cent. This wet year was followed by 3 years of rainfall below the normal. The driest season in the last 10 years—1912, with 7.90 inches—was preceded by a year in which 19.37 inches fell. At Holbrook, where the mean of the annual rainfalls is 10.94 inches, 5.20 inches was recorded for 1904, and more than three times as much (17.63 inches) for 1905. The corresponding figures for Fruitland are 3.33 and 9.17 inches, and for Hite 4.44 and 12.36 inches. Over the entire plateau province 1905 and 1911 were seasons of excessive rainfall, causing in the latter year destructive floods in all the larger valleys. It is interesting to note, however, that during the flood year of 1911 the rainfall at Tuba was about normal.

For a region whose maximum precipitation is insufficient for agriculture and in places for grazing without irrigation these great variations from year to year are matters of concern. Of even greater significance are the differences in amount received in corresponding months from year to year (fig. 2). At Fort Defiance the precipitation for January ranges from 0 to 2.20; for May, from a trace to 3.38; and even for August, the wettest month in the year, from 0.62 to 4.03 inches. At Fort Defiance June is one of the three driest months, but the wettest month on record at this station is June, 1903, when 4.67 inches fell. At Holbrook the precipitation in April for different years ranges between 0 and 1.51 inches; the July measures are 0.16 and 4.44; and the December precipitation of 2.32 for 1906 is represented by a "trace" in 1907. At Tuba the difference for the months of various years is as follows: January, 0 to 2

inches; February, "trace" to 2.03; March, 0.16 to 1.59; April, 0 to 2.58; May, 0 to 0.75; June, 0 to 0.75; July, 0.19 to 1.90; August, 0.09 to 1.66; September, 0 to 1.98; October, 0.15 to 1.84; November, 0 to 2.92; December, 0 to 1.77. Similar contrasts occur in the records of other stations.

SEASONAL DISTRIBUTION.

The diagrams of seasonal distribution of rainfall (fig. 3) show that for the Navajo country in general summer is the rainy season and spring the dry season, and that fall and winter occupy intermediate positions. Tuba, Aneth, and Hite are exceptions to this rule. There is in reality one dry season, followed by one wet period, with two seasons of intermediate grade, which, however, do not correspond with the seasons as that term is conventionally used. The period including July, August, and September is the season of maximum precipitation, during which time 37 per cent of the total rain falls; and the months of April, May, and June constitute the driest group, with 12 per cent of precipitation. Rainfall during the period January to March is slightly greater than for October, November, and December, these seasons receiving, respectively, 25 and 26 per cent of the annual precipitation.

It will be noted that the season of least rainfall, April to June, is the growing season for most crops, and that therefore the seasonal distribution of rain is unfavorable for agriculture or for the vigorous reproduction of many grasses. Half an inch of rain per month for the period April, May, and June is an unusually large precipitation for most parts of the reservation, and during many years the combined precipitation of these three months is less than one-half inch. Moreover, plants obtain only a portion of this meager supply, for evaporation is most effective during the clear, dry, hot days of early summer. The moisture in the ground, supplied by the rains of winter supplemented by the scattered showers of

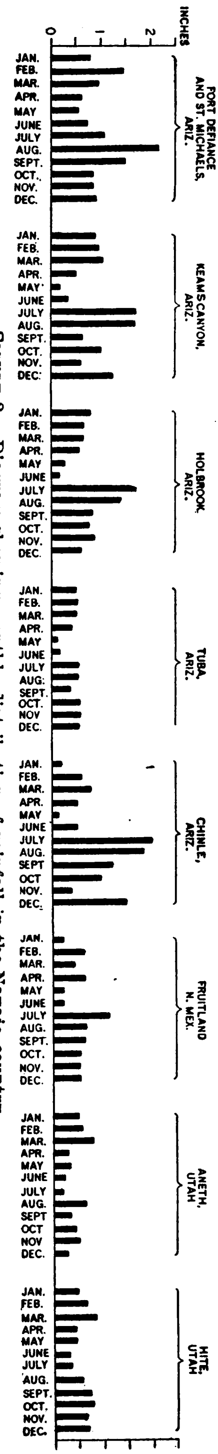


FIGURE 2.—Diagram showing monthly distribution of rainfall in the Navajo country.

spring, is sufficient to allow seeds to germinate and to send th stalks above ground, but is insufficient to bring a crop to matur The rainfall of July becomes therefore the critical climatic fac in the life of the Navajo. If his prayers to the rain gods answered his corn crop is assured, and grass springs up from

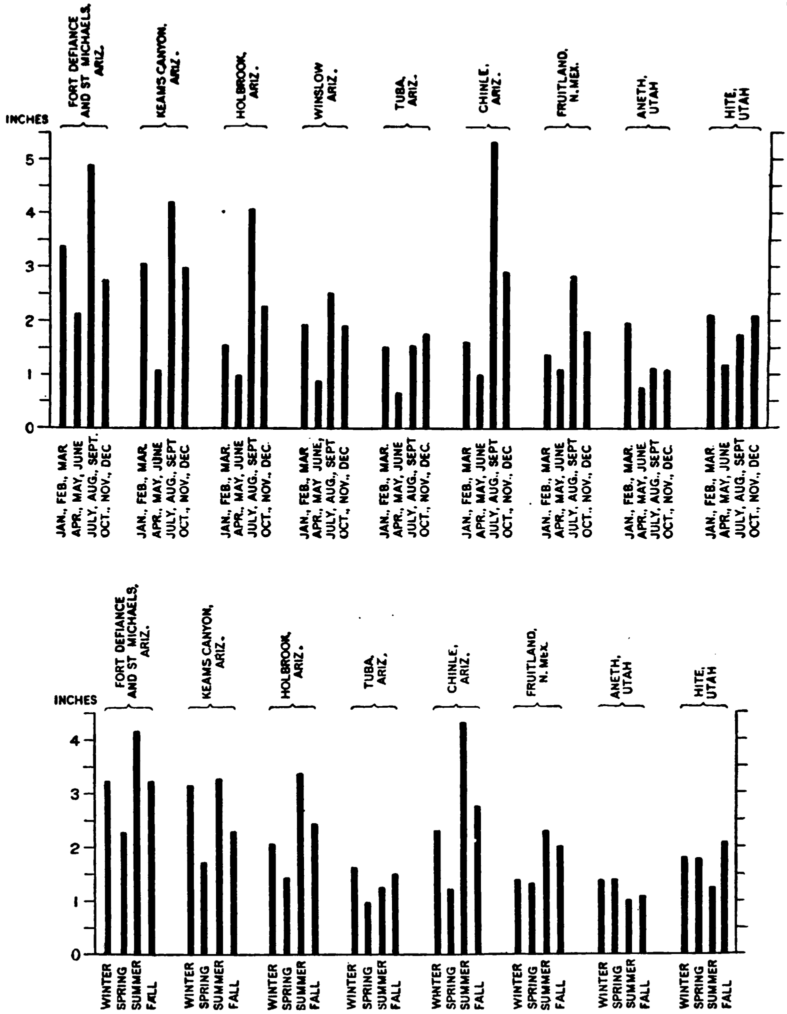
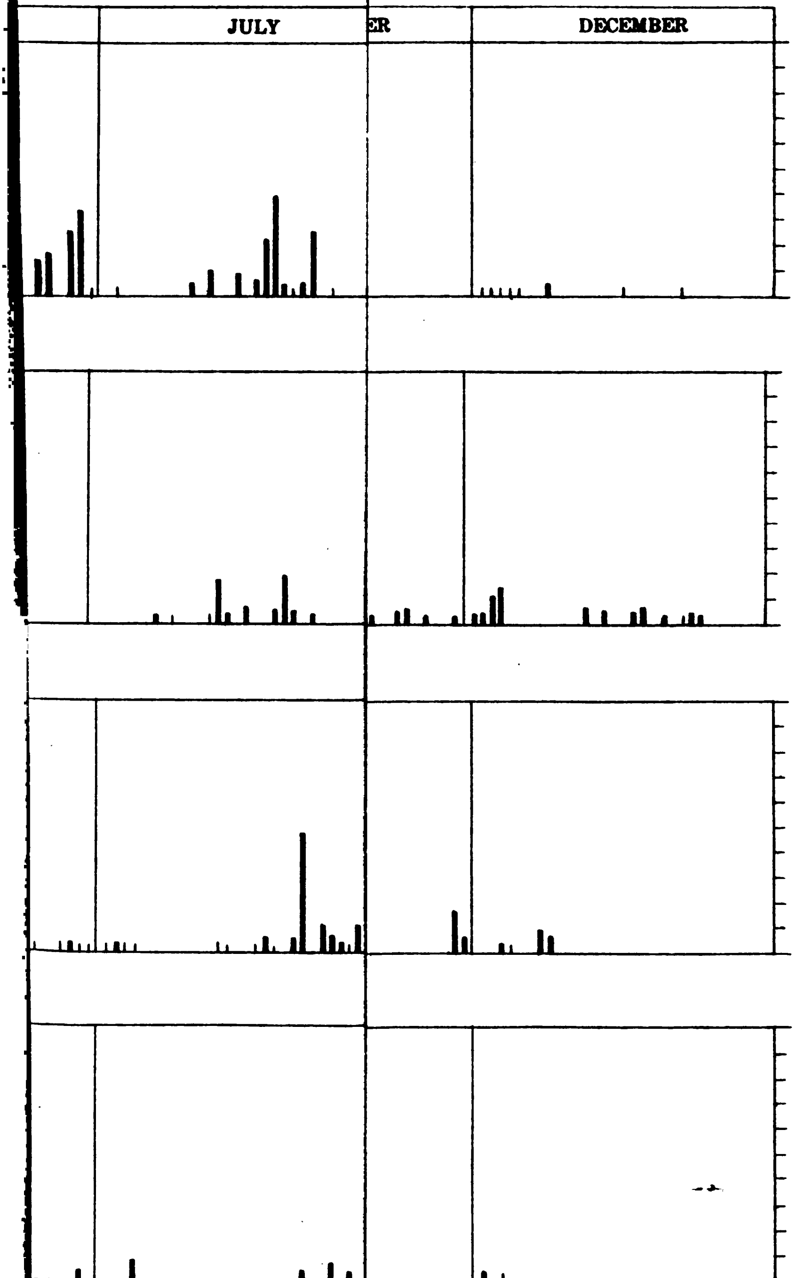


FIGURE 3.—Diagram showing seasonal distribution of rainfall in the Navajo country.

desert floors; if his prayer is denied the crop is a failure. The tables show that for the periods under observation less than 1 inch of rain falls during July in 6 years out of 18 at Fort Defiance and St. Michaels, 4 out of 10 at Keams Canyon, 5 out of 22 at Holbrook, 4 out of 5 at Winslow, 11 out of 13 at Tuba, 4 out of 11 at Fruitland, and 5 out of 9 at Aneth. For a large part of the reservation corn, without irrigation, fails to mature every second to every fourth year.



ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

DAILY RAINFALL

House Doc. ; 64th Cong., 1st. Sess.

In the Painted Desert and on Kaibito Plateau natural agriculture is not attempted even by the optimistic Navajo. At Chinle, on the other hand, an inch or more of rain falls each July, and total failures of crops at this point are of rare occurrence.

CHARACTER OF RAINSTORMS.

Gentle rains lasting more than 24 hours are of very rare occurrence in the Navajo country. Only one such was experienced during my four seasons' work. The characteristic storm is the thundershower of extreme violence, lasting usually less than an hour. The area covered by the shower is frequently only a few square miles, and on two occasions showers of 20 to 30 minutes' duration resulted in wetting less than 300 acres. Many of the showers result in a heavy downpour, and the total precipitation for a month is not infrequently the result of a single shower. (See Pl. XVI.) On the other hand, during the month of August, 1911, our party experienced showers for 22 days in succession. These showers occurred regularly between 11 o'clock and 1 o'clock, and the precipitation from each shower ranged from 0.01 to 0.20 inch. Generally the intense heat preceding a shower is reestablished within an hour or two after rain has ceased, especially at elevations below 6,000 feet. So quickly is clothing dried after one of these showers that it was found unnecessary to carry tents even during the rainy season.

Lightning is the almost invariable accompaniment of summer showers and constitutes a real danger to travel. During August, 1911, six Indians were killed by lightning and on two occasions my camp equipage was hit by a bolt. Lightning ranks first as a cause of forest fires in this region, and partly burned trees are everyday sights in the highland forests. The Weather Bureau station at Flagstaff has recorded more than 50 thunderstorms a year for the period 1904–1911. My records of thunderstorms for the Navajo Reservation during the field seasons 1909, 1910, 1911, and 1913 are 38, 26, 33, and 23, respectively, and it is believed that the annual number exceeds 40—an estimate much in excess of the figure (20) given by the Weather Bureau.[1]

TEMPERATURE.

The elements of most significance in the temperature of the Navajo country are given in the following tables compiled from records obtained through the United States Weather Bureau, at stations within or on the immediate border of the Navajo and Hopi reservations. All these stations are in charge of voluntary observers, and many of the records are incomplete and some may be inaccurate. The data at

[1] Climatology of the United States; U. S. Weather Bureau Bull. Q, pl. 28, 1906.

hand, however, are considered sufficient to indicate the value to be given to the temperature element in the climate of the Navajo Reservation. The figures represent degrees Fahrenheit.

Temperature at Fort Defiance-St. Michaels, Ariz., 1899–1913 (except 1910).

[On the edge of Defiance Plateau. Elevation, 6,900± feet.]

	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	14	27.9	30.9	38.3	43.8	52.8	62.9	68.2	66.9	54.6	44.3	38.4	27.1	47.6
Highest monthly mean	14	35.6	37.4	43.2	48.2	56.8	66.5	72.4	70.3	70.5	64.9	59.4	51.6	63.6
Lowest monthly mean	14	20.0	19.8	33.4	42.2	49.4	58.4	64.4	64.6	53.7	43.0	33.2	18.6	44.1
Highest temperature	12	57	65	75	78	85	98	97	96	86	78	65	59	98
Lowest temperature	12	−12	−24	1	12	20	26	31	39	22	10	−6	−20	−24

NOTE.—Records for the years 1899–1905 were taken at Fort Defiance; those for 1906–1913 at St. Michaels. The two stations are 8 miles apart and have nearly identical altitude and topographic setting.

Days on which temperatures above 90° were recorded are distributed as follows: 1910, May, 2 days; June, 3 days; July, 14 days; August, 3 days; September, 1 day. 1911, July, 1 day; August, 5 days.

Days with temperatures below 15° are: 1910, December, 4 days; January, 18 days; February, 10 days. 1911, November 8 days; December, 25 days, including a consecutive period Dec. 13–30; January, 7 consecutive days; February, 5 consecutive days.

Temperature at Holbrook, Ariz., 1891–1900, 1904–1913 (except 1910).

[Little Colorado Valley. Elevation, 5,069 feet.]

	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	20	33.1	38.7	45.6	52.6	60.2	65.4	74.8	74.5	67.0	53.9	42.6	33.0	54.2
Highest monthly mean	20	41.8	44.8	49.6	56.6	64.2	72.4	79.1	79.2	70.5	56.6	47.0	39.2	63.3
Lowest monthly mean	20	22.0	34.2	41.2	50.2	57.0	65.0	71.6	72.2	64.6	52.0	38.2	18.6	51.9
Highest temperature	18	66	78	89	94	97	105	106	103	100	89	81	73	106
Lowest temperature	18	−11	−6	−4	13	21	29	44	45	27	16	−8	−21	−21

Temperature at Keams Canyon, Ariz., 1894–95, 1906–1909, 1911–1913.

[In a narrow canyon cut in the southern edge of Black Mesa. Elevation, 6,600 feet.]

	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	9	31.4	34.5	33.9	48.5	55.7	61.8	60.6	69.4	61.6	52.6	40.4	30.2	51.8
Highest monthly mean	9	36.8	41.6	45.1	49.8	58.8	71.0	76.4	74.3	65.0	55.6	45.5	36.4	62.7
Lowest monthly mean	9	25.5	27.8	35.7	44.1	51.7	61.8	68.0	69.0	58.0	47.8	37.0	21.7	48.2
Highest temperature	3	55	67	77	79	80	90	101	92	90	89	72	60	101
Lowest temperature	3	−2	−8	10	20	27	28	43	43	25	17	9	3	−8

Temperature at Tuba, Ariz., 1897–1913 (except 1910).

[On the southwest edge of Kaibito Plateau in the midst of a desert overlooking the Little Colorado Valley. Elevation, about 4,700 feet.]

	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	16	32.7	38.5	46.1	53.8	61.6	70.9	77.0	75.2	67.1	54.4	43.2	30.5	52.1
Highest monthly mean	16	43.2	45.4	54.4	58.4	65.4	76.4	82.6	77.1	76.5	58.8	48.3	39.2	61.5
Lowest monthly mean	16	23.2	30.2	40.7	48.6	55.6	66.8	72.6	73.2	61.9	49.4	35.6	21.7	34.0
Highest temperature	12	68	73	85	88	99	104	105	108	100	95	81	64	108
Lowest temperature	12	−7	−3	12	21	26	34	40	48	28	18	10	−13	−13

Temperature at Chinle, Ariz., 1909, 1912, 1913.

[On the east side of the broad Chinle Valley, at the mouth of Canyon de Chelly. Elevation, about 5,200 feet.]

	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	3	29.9	33.2	26.8	47.2	57.0	66.8	70.4	69.6	58.3	33.8	40.4	23.6	49.1
Highest monthly mean	3	37.2	35.6	41.6	47.9	59.0	69.2	74.9	72.8	62.8	52.4	42.0	25.8	50.8
Lowest monthly mean	3	23.2	30.6	38.9	46.0	54.9	64.6	66.4	65.6	53.4	49.0	38.0	21.3	47.8

Temperature at Fruitland, N. Mex., in San Juan Valley, 1903–1909, 1911–1913.

[Elevation, about 5,200 feet.]

	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	10	30.8	35.2	43.9	55.6	52.1	67.3	72.5	71.5	62.5	50.5	39.3	26.6	46.1
Highest monthly mean	10	35.6	43.4	47.7	52.8	61.0	68.8	74.6	74.0	67.1	52.6	41.8	35.0	52.6
Lowest monthly mean	10	25.7	26.8	39.6	46.2	54.4	66.3	71.2	70.0	61.0	46.6	36.0	18.0	43.7
Highest temperature	13	71	86	83	92	97	108	110	101	95	86	90	79	110
Lowest temperature	13	−9	−14	6	11	18	31	34	41	27	11	−1	−6	−14

Temperature at Hite, Utah, 1900–1909, 1911.

[In the canyon of the Colorado at the mouth of Trachyte Creek. Elevation, about 3,500 feet.]

	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	11	32.5	43.0	51.2	59.2	66.9	68.2	84.2	82.5	72.5	53.9	45.9	31.1	60.6
Highest monthly mean	11	41.0	51.4	54.6	61.8	72.8	83.0	89.6	86.1	75.6	64.0	47.8	42.2	65.1
Lowest monthly mean	11	33.5	32.4	47.0	56.2	63.1	72.4	82.1	80.2	71.8	55.1	44.3	33.2	58.2
Highest temperature	9	63	81	86	94	98	111	115	110	104	91	76	76	115
Lowest temperature	9	2	6	18	28	48	59	65	62	48	29	20	7	2

Temperature at Aneth, Utah, in San Juan Valley, 1901–1907, 1911–1913.

[Elevation, about 4,700 feet.]

	Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	10	30.3	37.8	46.2	49.1	62.8	72.2	78.8	77.5	67.3	55.4	42.3	23.8	54.0
Highest monthly mean	10	38.3	44.4	51.4	57.0	66.3	74.8	81.6	79.7	69.4	64.1	43.9	39.0	61.3
Lowest monthly mean	10	21.0	27.2	41.6	53.0	60.2	70.5	74.4	76.2	64.2	52.4	39.5	25.0	50.8
Highest temperature	8	63	77	83	86	93	105	104	106	100	88	67	67	106
Lowest temperature	8	−10	2	14	19	31	38	45	42	32	22	11	−2	−10

Frost record in the Navajo country.[a]

Place.	Years.	Average date of first killing frost in autumn.	Average date of last killing frost in spring.	Earliest date of killing frost in autumn.	Latest date of killing frost in spring.
Fort Defiance	7	Sept. 17	June 11	Sept. 15	July 7
St. Michaels	5	Sept. 13	June 15	Aug. 29	June 23
Keams Canyon	9	Sept. 23	June 10	Sept. 13	June 14
Tuba	16	...do....	May 13	Sept. 19	June 5
Holbrook	20	Oct. 11	May 11	Sept. 17	June 13
Chinle	2	Sept. 25	May 23	...do....	May 31
Fruitland	10	Sept. 20	Apr. 13	...do....	Apr. 27
Aneth	10	Sept. 21	...do....	Sept. 12	May 13
Hite	12	Oct. 20	Mar. 21	Oct. 19	May 24

[a] Computed from miscellaneous records in annual reports of United States Weather Bureau.

The influence of elevation and topographic position on temperature is shown by a comparison of the tables for Fort Defiance-St. Michaels with those for Holbrook, Aneth, and Hite. Fort Defiance-St. Michaels, at an elevation of nearly 7,000 feet, has a mean annual temperature of 47.6°. The thermometer rarely goes above 90°, and the highest temperatures recorded for 12 years are June, 98°; July, 97°; August, 96°; while for four or five months in a year the thermometer falls below 20°, and —24° has been recorded. Holbrook, elevation 5,069 feet, has an annual mean of 54.2°; for Aneth, elevation 4,700 feet, the mean is 54.0°; and for Hite, elevation 3,500 feet, 60.6°. At this last station zero temperatures are not recorded. The range between the highest and the lowest monthly means is lowest for Chinle, 3°, followed in order by Hite, 4.9°; Fruitland, 8.9°; Aneth, 10.5°; Holbrook, 11.4°; Keams Canyon, 14.7°; Fort Defiance-St. Michaels, 19.5°; and Tuba, 27.5°. These figures of mean annual temperature and the range between the lowest and the highest average monthly means are not unlike those generally prevailing in temperate latitudes, and give, therefore, little indication of the temperatures experienced in this region.

The annual and daily ranges of temperature are of greater significance. The maximum annual range recorded for Keams Canyon is 109° (101° to —8°); for Hite, 113° (115° to 2°); for Aneth, 116° (106° to —10°); for Tuba, 121° (108° to —13°); for Fort Defiance-St. Michaels, 122° (98° to —24°); for Fruitland, 124° (110° to —14°). The greatest range (127°) is at Holbrook, where a July temperature of 106° is offset by the low December record of 21° below zero. At all points on the reservation below 7,000 feet, temperatures exceeding 100° normally occur for 10 to 20 days each year, and in the Painted Desert, in the lower San Juan Valley, and along the Colorado Canyon such temperatures were experienced by our party for 3 to 6 days in succession. At such times the temperatures in the sun are almost intolerable. The surface soil reaches 140°–160°, and instruments, saddles, notebooks, and camp utensils can not be handled without pain. Except within the Little Colorado and San Juan valleys, and to a less extent in other canyons, temperatures below zero are normal for December, January, and February, and at Fort Defiance and Holbrook zero weather for 5 to 6 days in succession has been experienced.

High annual temperature ranges are accompanied by great daily range. A daily range of about 40° is probably common to the whole reservation; ranges of 50° have frequently been experienced; and on a few occasions my party has worked at temperatures exceeding 80°, only to find ice in the camp buckets on the following mornings. A worker in this field soon learns that an ample supply of bed

blankets is required even during the scorching summer months. Sudden changes during daytime are infrequent, except when thundershowers cool the air for a few hours. On one occasion during July, a temperature of 96° at 2 o'clock was followed within an hour by a hailstorm, which whitened the ground and lowered the temperature to a point where vigorous exercise was required to keep our limbs from becoming numb.

Fortunately for man and beast, high temperatures and great daily range are accompanied in this region by dry air and cloudless skies. The mean relative humidity at Flagstaff[1] is 62 per cent, being lowest (39 per cent) during June, the driest and, during some years, the hottest month. For the Navajo Reservation these figures are doubtless even lower. High humidity and high temperature were found not to be contemporaneous, with the result that heat, though distressing, is not enervating and oppressive. A hot air bath, not a steam bath, is part of the daily routine.

The average date of first killing frost of autumn ranges from September 13 at St. Michaels, to October 20 in the Colorado Valley; and the average date of the last killing frost of spring ranges from March 21 at Hite, to June 15 at St. Michaels. The stations under observation (see pp. 64–65), therefore, have in normal years a growing season as follows: St. Michaels, 89 days; Fort Defiance, 98 days; Keams Canyon, 105 days; Chinle, 124 days; Holbrook, 127 days; Tuba, 133 days; Fruitland, 161 days; Aneth, 161 days; and Hite, 201 days. This long growing season, where water has been made available as at St. Joseph, Fruitland, and Tuba, coupled with high temperatures, has favored alfalfa, corn, and fruit raising on an extensive scale. When, however, a period of several years is considered, it appears that the normal length of the growing season may be much shortened. Thus the growing season may be reduced to 96 days at Holbrook, and shortened by two weeks at Tuba; and Fort Defiance may have killing frost during every month of the year except August.

The bearing of these figures on agriculture and irrigation may be seen from the fact that corn requires, on the average, 90 to 150 days, and fruit an even longer time to reach maturity.

WIND.

Extensive areas of dunes and rippled flats eolian sands, widely spread over the Navajo Reservation, bear witness to the presence of winds. Rocks polished and etched by wind-blown sand (Pl. XVII, *A*), vegetation buried waist deep, and fields of corn with leaves cut into shreds, are everyday sights. Sand storms are fre-

[1] United States Weather Bureau Bull. W, vol. 1, 1912.

quent and whirling columns of dust reaching high into the air may be counted by the dozens on clear summer days. During the larger storms the sky is darkened and the swiftly driven sand grains impel man and beast to seek shelter in some friendly arroyo. These storms are at their worst in the Painted Desert, along the Tusayan Washes, and on the Kaibito Plateau. The oasis of Tuba is walled in on the west by sand, piled against a windbreak made of trees, and the school grounds at Leupp are alternately buried and reexcavated. Fine sand, driven by strong winds, finds its way into the best constructed buildings.

The nervous irritation caused by the hot, stifling winds calls to mind the Spanish proverb: "Ask no favor while the solano blows." In the picturesque Navajo mythology the Wind People were sent to dry up the earth and "Wind and Night" (sand storm) is the most dreaded expression of these powers for evil.

The records available for the Navajo Reservation show that the prevailing direction of wind is southwest for all stations on the reservation except Keams Canyon, where the low winds measured are directed eastward by a narrow, rock-walled gorge. Wind velocity has been recorded at Flagstaff, 40 miles beyond the Navajo Reservation line.

Prevailing direction and velocity of wind.

Direction.

Place.	Length of record in years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Holbrook...	9	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.
Tuba.......	12	sw.	N...	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.
St. Michaels.	12	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.	sw.
Keams Canyon.......	3	sw.	w...	w...	w...	w...	sw.	w...	s....	w...	w...	SE..	E...	w.

Average velocity in miles per hour.

Flagstaff....	5	6	7	9	9	10	9	7	5	7	6	7	7	

SOIL.

On the Navajo Reservation two types of soil are found—residual or local soils, which have resulted from decomposition of the rocks immediately underlying the surface; and transported soils, which have been carried by natural agencies from their place of origin and redeposited elsewhere. Scantiness of vegetation, severe showers, rapid run-off, and strong winds—features characteristic of this part of the country—are unfavorable for the development and retention of soil in place, and accordingly transported soil predominates. Soil

A. WIND-SWEPT ROCKS, RAINBOW PLATEAU, NORTH OF NAVAJO MOUNTAIN.

Photograph by A. R. Townsend.

B. WEST SLOPE OF DEFIANCE PLATEAU.

Typical view in zone of sage and greasewood, with scattered groves of piñon and cedar; elevation 5,200 feet.

A. PIUTE CANYON AT UPPER CROSSING.

B. TYPICAL VIEW IN ZONE OF PIÑON AND CEDAR, 6,000 FEET ABOVE SEA LEVEL.

Photograph by Schwemberger.

weathered directly from the underlying rock forms a mantle a few inches thick on the broad interstream spaces which mark the flat tops of the Chuska Mountains, of Defiance, Dutton, and Chaco plateaus, and of Black and Segi mesas. Large patches of residual soil may be found also on Carrizo and Navajo mountains, in Monument and Chuska valleys, and to a less extent elsewhere. Bare rock, however, predominates on the tops and slopes of the smaller mesas and ridges; the canyon walls are generally without soil; and hundreds of square miles along the Little Colorado and San Juan rivers, on Kaibito and Rainbow plateaus, and in the Hopi Buttes province, have prevailingly bare rock floors. It is probable that the reservation could be traversed along a selected route from Carrizo Mountain to Lee Ferry and from Grand Falls to Bluff without setting foot on soil of local origin.

Transported soil, however, is widespread. The broad washes and their innumerable tributaries are flooded with stream-borne débris to depths exceeding 100 feet. Alluvial soil is also displayed in fans and slopes along the valley sides and in terraces clinging to canyon walls, and a small amount of transported soil marks the beds of extinct and ephemeral lakes. Wind also has played a part in distributing surface materials. Eolian soils in the form of dunes, ridges, and rippled flats are prominently displayed along the Little Colorado, in the Tusayan Washes, on Moenkopi, Kaibito, and Shato plateaus, and to a less degree in the Chinle Valley. The west and south sides of the reservation are most heavily coated with wind-blown soil, but "blow dust" is found on highland and lowland alike, and it is probable that the strong prevailing southwest winds carry impalpable dust to all parts of the reservation.

The soil of the Navajo country is derived from rocks relatively poor in mineral plant food. Limestone underlies probably less than 5 per cent of the area, occurring only in the strata of Carboniferous age and in certain beds of the Chinle formation and of the La Plata group.[1] The shales and sandstones of the Moenkopi formation contain relatively little plant food and are in most places charged with gypsum and other objectionable salts. The Shinarump conglomerate furnishes no soil of value to plants, and the shales of the Chinle formation develop characteristically into infertile "badland" areas. The sandstones of both the La Plata group and the McElmo formation are prevailingly quartzose and are therefore sparingly provided with plant food. The Cretaceous strata—Dakota, Mancos, and Mesaverde—contain a higher proportion of mineral plant foods than any of the other formations represented on the reservation, and the lavas (largely basaltic) furnish a soil of high fertility. However, in spite of its origin, the soil of the reservation

[1] The distribution of the rock formations is shown on the geologic map, Pl. II, in pocket.

A. PIUTE CANYON AT UPPER CROSSING.

B. TYPICAL VIEW IN ZONE OF PIÑON AND CEDAR, 6,000 FEET ABOVE SEA LEVEL.

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is not lacking in fertility—a condition which is due largely to the arid climate. The bits of plant food sparingly distributed in the rocks are accumulated in the soils of the washes and alluvial fans. Here the food is stored in large quantities and for long periods, because continuous, vigorous ground-water movement is lacking, and the leaching of soluble constituents is correspondingly checked.

No detailed studies of the soils of the Navajo country have been made, but incomplete analyses of several samples collected in haphazard fashion from Chuska Valley, Chinle Valley, and the Tusayan Washes revealed lime, potash, phosphoric acid, sulphuric acid, and nitrogen in amounts fairly typical for soils of the arid Southwest. The following analyses of soils were made by Dr. Loew.[1] The first is a sample of the soil cultivated by the Hopis in the vicinity of Oraibi; the sample from Chevelon Fork[2] is from deposits weathered from sandstones of "Triassic age" (Chinle formation?).

Analysis of soils from Hopi villages.

Potash	0.072
Carbonate of lime (lime=1.665)	2.970
Phosphoric acid	.031
Soda	Trace.
Lithia	Trace.
Alumina, oxide of iron and magnesia	2.327
Total extract by hydrochloric acid	5.40
Insoluble	94.60

Analysis of soil from Chevelon Fork.

Sand	53.10
Silt with clay	43.55
Hygroscopic moisture	1.89
Chemically bound water and organic matter	1.46
	100.00
Potash	0.092
Soda	.010
Lime	.319
Phosphoric acid	.070
Sulphuric acid, magnesia, alumina, and oxide of iron	2.559
Insoluble in hydrochloric acid (chiefly quartz sand)	93.550

That the soil of the reservation possesses fertility is amply demonstrated by the vigorous natural growth of perennials and annuals where water is present and by the fact that the Hopis and their ancestors, the cliff dwellers, have cultivated crops of corn, peaches, and melons without irrigation, and even in sand dunes. The fer-

[1] Loew, Oscar, U. S. Geog. Surveys W. 100th Mer. Rept., vol. 3, pp. 585, 586, 1875.

[2] Chevelon Fork, according to Sitgreaves, received its name from a French trapper "who died upon its banks from eating some poisonous root."

tility of the soil is renewed by continuous redistribution of alluvium, by showers and seasonal rains, and by wind—a process which tends also to incorporate within the soil the vegetation which springs up rapidly where conditions allow. Large quantities of sheep manure, at present little used, are available for fertilization.

As in other arid regions, the ingredient lacking in Navajo soils is water. The dry air and loose soil allow the ready passage of moisture to the surface, and during the dry season the water table sinks to a depth which makes natural farming in this region unprofitable. Experiments in dry farming have produced fairly satisfactory results, and where water is applied systematically the soil responds with alacrity, as has been abundantly demonstrated by the Mormons at Bluff, Tuba, and St. Joseph, and by the Government farmers at Fort Defiance, Chinle, Shiprock, and elsewhere. In planning for the future of this country it should be borne in mind that the "dull, lifeless soil," "hopelessly barren land," and "worthless, bare stretches" of the early explorers and chance tourists are terms not necessarily synonymous with infertility. On the other hand, it appears that the available supply of water is insufficient, even after full development, to reclaim any large part of this otherwise fertile land.

FLORA.

GENERAL RELATIONS.

The barrenness of the Navajo region impressed itself on the early explorers. Simpson[1] pays his respects to the Chuska Mountains and Chuska and Chinle valleys in the following terms:

> The primary mountains are generally destitute of other sylva than pine and cedar, most frequently of a sparse and dwarfish character. * * * The sedimentary rocks are almost universally bare of vegetation, except that of a sparse, dwarfish, sickening-colored aspect, and can not be regarded as a general thing * * * without a sensation of loathing.

Sitgreaves[2] states: "I can add very little to the information afforded by the map, almost the entire country traversed being barren and without general interest."

Whipple[3] classifies the land in a belt 30 miles wide and 110 miles long, between Campbell Pass and Flax River (Little Colorado) as follows: "Woodland, one-tenth; cultivatable soil, one-thirtieth; rock hills, one-tenth; prairies and pasture, seven-tenths."

The vegetation of the country traversed by Simpson, Sitgreaves, and Whipple has doubtless changed little during the last 60 years.

[1] Expedition into the Navajo country: 31st Cong., 1st sess., Ex. Doc. 64, 1850.
[2] Expedition down the Zuni and Colorado rivers: 33d Cong., 1st sess., Ex. Doc., 1854.
[3] U. S. Pacific R. R. Expl., vol. 3, pt. 2, p. 50, 1854.

Further acquaintance with the reservation, however, brings to view a widely distributed and widely varied flora of peculiar ecologic interest, which remains a virgin field of study.

Within the limits of the Navajo country the factor of latitude has little effect on plant life. Topography and altitude with their attendant climatic controls determine the character of the plant life and the boundaries of ecologic provinces. For the region as a whole four zones of vegetation are readily distinguished:

1. Zone of cottonwood, cactus, and yucca; altitude, 3,500–5,000 feet; type area, Little Colorado Valley. Within this zone vegetation is scanty and over large areas very inconspicuous. "Flat-leaved" and "globular" cacti are abundant; yucca is common; grass is scanty and commonly in detached tufts; sage and greasewood are of small size; scrub juniper and piñon are relatively rare. During the rainy season there is a profusion of annuals, among which Mariposa lily, yellow sunflowers, and related Compositæ are abundantly represented. In places fields several acres in extent of yellow flowers were noted. Wild flax is common.[1]

2. Zone of sagebrush (Artemisia) and greasewood (Sarcobatus); altitude, 5,000–6,000 feet; type locality, upper Pueblo Colorado Wash. Sage within this zone attains heights of 4 or 5 feet and in places is so closely spaced as to render travel difficult and may occupy the surface to the exclusion of trees. Besides the ever-present sage and greasewood, grass is fairly abundant in this zone. Patches of piñon and juniper are irregularly distributed, usually along rocky ridges, but are in general of "scrub" size (Pl. XVII, *B*, p. 68).

3. Zone of piñon (*Pinus edulis*) and juniper (*Juniperus monosperma*); altitude, 6,000–7,000 feet, the juniper in general occurring at lower altitudes than the piñon; type locality, south edge of Black Mesa. Much of the piñon and juniper is of scrub size, but trees 12 to 20 inches in diameter are not uncommon and would yield 1 to 25 cords of firewood per acre. Sagebrush, and to a less extent greasewood, usually of strong growth, occupy open spaces. Groves of piñon surrounding parks of sage is the ordinary arrangement. Scrub oak and box elder are also found. Pine and juniper (*Juniperus scopularum*) and aspen (*Populus tremuloides*) are found in a few well-watered canyons. Grass in tufts and scattered mats grows everywhere except in the densest shade (Pl. XVIII, *B*, p. 69).

4. Zone of yellow pine; altitude, 7,000–8,500 feet; type locality, Defiance Plateau (Pl. XIX). The pines form solid forests over many square miles. The trees stand far apart and, as was long ago noted by Loew,[2] there is a singular absence of trees of intermediate heights. Englemann spruce and Douglas fir in groves of a few indi-

[1] An early Spanish name for the Little Colorado River is Rio de Liño. Ives (1861) uses the term Flax River. The Navajo name is Tolchico, "red water canyon."

[2] U. S. Geog. Surveys W. 100th Mer. Rept., vol. 3, pp. 603–604, 1875.

viduals are found here and there clinging to canyon walls, especially on north slopes, and Gambel oak (*Quercus gambelii*) in close-set patches attains considerable prominence. Quaking aspen commonly occurs in the upper mountain valleys. Fine grass is common.

Yellow pine is practically absent from the higher parts of Black Mesa and the Segi Mesas at altitudes where they are to be expected. Lack of water rather than unfavorable temperature is believed to account for the absence of pine at elevations between 7,000 and 7,700 feet on Black Mesa. In support of this view, the presence of fir and aspen at this elevation is cited by Mr. Johnson.[1] An additional bit of evidence is the fact that in the canyon of Segi Mesas and in sharp indentations on the side of Black Mesa pines grow vigorously.

5. Zone of Engelmann spruce; altitude, 8,500 to 10,416 feet (the highest summits); type locality, Navajo Mountain. Outside of the type locality small groves of spruce were noted on Carrizo Mountain and the Chuska Mountains, and on Dutton Plateau. Within the Navajo Mountain forests are spruce trees 12 to 30 inches in diameter and 70 to 80 feet high. In open spaces beneath the trees blackjack, oak, willow, poplar, ground juniper, manzanita, sage, gooseberry, and raspberry attain luxuriant growths, while flowers in large variety are embedded in the grass. The profusion of flowers at moderate altitudes is remarkable for variety of species and abundance of individuals. On the Chuska Mountains Simpson[2] collected 90 varieties within 24 hours, and 22 plants were found in blossom on Navajo Mountain.

The boundaries of the zones roughly outlined above are subject to considerable shifting in harmony with topographic position. In general the zone boundaries descend on the north and east, but plant societies characteristic of one zone may be found within another zone, appearing strangely out of place. Piñon represented by individuals was found in the Glen Canyon at 3,500 feet and on Carrizo at 9,000 feet; cacti are found at all elevations, and the cottonwood, abundant along the San Juan and the Little Colorado, reappears up to 6,000 feet.

Cotton was cultivated by the cliff dwellers and their descendants, and the corn frequently found in ruins testifies to the antiquity of agriculture in this region.[3] Peaches growing wild in Nazlini and de Chelly canyons were probably introduced by the Spaniards. Beale[4] reports that potatoes were found growing wild at Fort Defiance.

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[1] Personal communication from Mr. Don B. Johnson, of the Forest Service.

[2] Expedition to the Navajo country, p. 96, 1850.

[3] In an ancient ruin near Tolchico burned corn is embedded in fragments of porous, baked adobe, locally called "lava." Similar occurrences may have given rise to a popular notion, often repeated in books of travel, that the homes of the cliff people were destroyed by volcanic eruptions.

[4] Beale, E. F., Surveys for a wagon road from Fort Defiance to the Colorado River, pp. 36–37, 1858.

FORESTS.

A map of the forests on the Navajo and Hopi reservations, prepared by G. A. Gutches, supervisor of forests, is reproduced as Plate XIX with the permission of the Commissioner of Indian Affairs. The following notes on the map are abstracted from Mr. Gutches's manuscript:

The area of spruce on Navajo Mountain is 4,500 acres, and will cut approximately 12,000,000 feet. The inaccessibility of this timber renders it of little value. "Merchantable yellow pine" occupies 235,500 acres, 80 per cent of which is covered by a good stand of mature timber averaging 21 inches in diameter breast high, and 80 feet in height, and will cut about 850,000,000 board feet of lumber. Roads for logging may be cheaply constructed. "Scattered yellow pine" on the Chuska Mountains and Defiance Plateau will yield 700,000,000 board feet of lumber in addition to 250,000 cords of fuel. "Piñon and scattered juniper" covers 1,250,000 acres. A denser growth of piñon at 7,000 feet thins out at about 6,200 feet, at which elevation juniper begins and constitutes about 20 per cent of the cut; 6,900,000 cords of fuel may be obtained from this forest type. "Scattered juniper and piñon" cover about 50 per cent of the area (3,400,000 acres) indicated on the map; 70 per cent of the stand is juniper and 30 per cent piñon. The two species together will yield 2,000,000 cords of fuel. "The reproduction of yellow pine over the yellow-pine types is very poor and scattered. For the most part the reproduction can be considered as nil. This is due to sheep and goat grazing. There are no signs of reproduction on the cut-over areas about the Navajo and San Juan Agency mills."

The wide spacing of trees and the absence of underbrush and of heavy grass practically eliminate the danger of forest fires arising from the usual causes. The region is, however, within the zone of maximum danger from lightning; 42,081 trees in the national forests of western New Mexico, northern Arizona, and southern Utah, including the plateau province, are reported to have been struck by lightning during a three-year period of observation.[1] On the Navajo Reservation trees broken or shattered or killed by lightning are common.

FAUNA.

Among the larger indigenous animals most frequently seen in the Navajo country are the rabbit, prairie dog, coyote, trade rat, field mouse, snakes of several species, including abundant rattlers, and a large variety of lizard; brown squirrels and chipmunks are found in the forests, where also wild cat, porcupine, wolf, fox, and bear are occasionally met. The Spanish padres, Sitgreaves[2] (1854),

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[1] Plummer, F. G., Lightning in relation to forest fires: U. S. Forest Service Bull. 111, 1912.

[2] Report of an expedition down the Zuni and Colorado rivers, 1854.

Lethermann[1] (1858), and Beadle[2] (1873) found antelope and black tailed deer in abundance. Beadle mentions also the gray fox and the beaver. The horns of mountain sheep were found at Navajo Mountain. The principal birds noted during the years 1909 to 1913 are the eagle, hawk, nighthawk, raven, wild turkey, crow, two species of duck, white and sandhill crane, piñon jay, three species of owl, catbird, swallow, and rock wren. On Navajo Mountain the robin, woodpecker, junco, woodthrush, tree sparrow, nutcracker, bluebird, and humming bird were seen. Insects, including tarantula and scorpion, are too common. Nearly the entire native fauna enters into Navajo animal worship. The eagle (Navajo, Atsa dine, the eagle people, who inhabit Yaghahoka, the heaven above), the owl (Navajo, Nasja, which plays the rôle of a spy), the bear (Navajo, Shash, the descendant of mythical monsters), and the snake are objects of special reverence. The attitude of the Navajo toward animals has resulted in the protection of many harmful species.

Previous to the Spanish invasion the natives appear to have had no domesticated animals except the dog. Navajo horses, obtained at first by raids upon Mexican settlers, are now abundant, and wild herds are occasionally seen. Burros, especially among the Hopis, are widely used; and nearly every Indian family has its flock of sheep and goats. Cattle raising is not as yet an important industry. The introduction of sheep greatly modified the dietary of Navajo and Hopi alike, and, with the occasional use of the horse, has replaced the deer and antelope, which are no longer seen in this region.

MINERAL WEALTH.

Prudden[3] states that no metal tools or utensils have ever been found in cliff ruins, and nowhere within the reservation have bodies of ores of high value been located. Mining camps established at various times have had short lives. The useless shaft on Carrizo Mountain, discarded machinery along the San Juan, and the abandoned workings west of White Mesa testify to the lack of commercial value in the widely distributed occurrences of gold and copper. The oil fields at Goodridge and Seven Lakes and recent locations on the Little Colorado have so far failed to justify the expenditure of large funds. Jewel garnets from the lower Chinle Valley and peridots from Buell Park and elsewhere find a ready market. The extensive coal fields of Black Mesa and of western New Mexico are of high value.[4]

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[1] Smithsonian Inst. Tenth Ann. Rept., 1855.

[2] The undeveloped West, 1873.

[3] Prudden, T. M., The Great American Plateau, 1907.

[4] Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 376–426, 2 pls., 1907.

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POPULATION AND INDUSTRIES.

The population of the Navajo and Hopi reservations estimated for 1912 is 32,488 Indians and 521 whites, distributed as follows:

Population, Navajo and Hopi reservations, 1912.

Agency.	Navajos.	Hopis.	Piutes.	Total Indian population.	Full blood.	Per cent afflicted with trachoma.	Per cent afflicted with tuberculosis.	Wear modern attire.	Speak English language.	White population.			Total white population.
										Officials.	Traders.	Missionaries.	
Leupp	1,200	......	......	1,200	1,200	20.83	4.08	800	75	15	30	14	59
Navajo	10,000	......	......	10,000	9,990	15.00	11.00	2,500	750	65	55	29	149
Pueblo Bonito	2,685	......	......	2,685	[a]2,680	53.32	1.71	[a]800	300	[a]16	[a]14	[a]2	32
San Juan	8,000	......	......	8,000	8,000	22.00	25.00	[a]1,000	200	60	55	7	122
Western Navajo	6,131	204	200	6,535	6,535	6.54	8.27	200	200	25	20	18	63
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	30,016	2,272	200	32,488	32,469	18.39	12.36	6,800	3,025	247	191	83	521

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To the physical environment of topography, climate, soil, native and introduced foods, and the water supply, the Hopi and the Navajo are in close adjustment. The 2,000 Hopi located on the high capes projecting from Black Mesa are agriculturists who, through centuries of experiment, have become surprisingly skillful in selecting fields and caring for their crops of corn, melons, and peaches. By dry farming and by irrigation, developed long before Spanish incursions, these people have maintained themselves and preserved their race from extinction in a singularly unfriendly environment. With incredible skill they have practiced the art of conservation of water, and that the mind of the race is intent on this one problem is shown by the organization of the clans and the elaborate ceremonies devised to enlist the cooperation of unseen powers which are believed to control the rainfall. Endless toil and endless prayer, both directed to increase and to preserve the precious water, constitute the life of the Hopi. (See Pl. XX.)

In marked contrast to the sedentary Hopi, the Navajo is a nomad, peculiarly adjusted to arid climates. His hogan is a temporary structure of poles and mud or of brush, and his life consists in following his flocks from place to place, where water and forage are available. With the coming of the whites, particularly within the last 25 years, many Navajos are making permanent homes and raising increased amounts of corn and forage crops by means of flood irrigation. As yet, however, the characteristic position of the Navajo is on horseback. The raising of sheep and the manufacture of blankets continues to occupy the attention of the men, women, and children of this tribe. These products are exchanged chiefly

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Pueblo Bonito	1,500,000	10,651	10,550	146,776	....	25,000
Western Navajo	3,020,347	12,200	2,500	150,000	48,200	15,000
Hopi	1,588,320	6,150	3,000	142,000	83,006	100,000
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Agriculture on unallotted lands in Navajo country, 1913.

Reservation.	Agricultural lands.								Grazing lands (acres).	Unfit for any purpose (acres).	Total acres.
	Irrigated (acres).	Irrigable but not irrigated (acres).	Irrigation not necessary (acres).	Miles of ditches.	Lands cultivated by Indians (acres).	Number of farms.	Average size of farm (acres).	Value of crops raised.			
Leupp	20	500	......	5	([a])	([a])	([a])	....	75,000	283,340	358,860
Navajo	......	10,000	......	......	10,000	2,000	5.00	$6,000	4,990,000	....	5,000,000
San Juan	5,000	......	......	100	5,000	1,000	5.00	162,100	3,810,000	....	3,815,000
Pueblo Bonito	([b])	([b])	([b])	......	400	200	2.00	1,338	1,500,000	....	1,500,100
Western Navajo	1,000	12,000	7,300	[c] 45	1,000	400	2.50	10,100	3,020,347	338,700	3,379,347
Hopi	10	......	3,999	[d] 50	4,000	1,500	2.67	22,000	1,588,820	720,000	2,472,320
	6,030	22,500	11,299	200	20,400	5,100	3.43	201,938	14,992,667	1,342,040	16,525,627

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In its broad outlines the geology of the Navajo country involves the geology of the Colorado Plateau province, and the problems of physiography, stratigraphy, structure, and volcanism relating to the region as a whole have been discussed by various writers. For

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STRATIGRAPHY.

The sedimentary strata within the limits of the Navajo country are of pre-Cambrian(?), Pennsylvanian, Permian(?), Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary ages. The relations of these systems and series and the formations which they embrace are represented in the generalized section (Pl. XXI).

Pre-Cambrian(?).—Within the area studied the oldest sedimentary formations whose age has been definitely determined are limestones of Carboniferous age. The lower contact of the Carboniferous is not exposed, but at Quartzite Canyon (locally called Blue Canyon) near Fort Defiance, quartzite unconformably underlies strata of Permian(?) age. In composition, structure, and degree of metamorphism this quartzite mass appears to be identical with the pre-Cambrian quartzite of the Colorado Canyon and is believed to be of equivalent age.

Pennsylvanian.—Within the canyon of the San Juan and at Grand Falls and several other points along the Little Colorado strata of buff and brown limestone are well exposed for study, and in the canyon walls this limestone (Kaibab) is underlain by other formations of the Aubrey group. Fossils collected at Goodridge, Utah, in 1909, and on the lower Little Colorado in 1910, taken in connection with later collections by Woodruff, have served to establish the Pennsylvanian age of these beds. The exposed Pennsylvanian strata—the Kaibab limestone and the Goodridge formation—differ materially in lithologic features.

Permian (?).—The beds between the Pennsylvanian limestone and the Shinarump conglomerate are assigned to the Permian (?) on the basis of Walcott's studies in the Kanab Valley and the discovery

U. S. GEOLOGICAL SURVEY

System and series		Formation
QUATERNARY		
TERTIARY	Eocene (?)	Chuska sandston
		UNCONFORMITY
		Tohachi shale
		UNCONFORMITY
CRETACEOUS	Upper Cretaceous	Mesaverde and later formations
		Mancos shale
		Dakota sandstone
		UNCONFORMITY
JURASSIC ?		McElmo formatio
JURASSIC	La Plata group	Navajo sandstone
		Todilto formation
		Wingate sandstone
		UNCONFORMITY
TRIASSIC		Chinle formation
		UNCONFORMITY
		Shinarump conglomera
		UNCONFORMITY
CARBONIFEROUS	Permian (?)	De Chelly sandsto
		Moenkopi formatio
		UNCONFORMITY
	Pennsylvanian	Aubrey group in Little Colorado River region, and Goodridg formation in San Jua River region (relation unknown)
		UNCONFORMITY
PRE-CAMBRIAN(?)		Quartzite

GENERALIZ

which have such a commanding influence in the plateau region farther west. In fact the fault in Monument Valley,[1] described by Woodruff as having a maximum throw of 200 feet, is the only example of faults exceeding 100 feet in vertical displacement so far known on the reservation. In the eastern part of the district the structural feature of primary importance is the De Chelly upwarp, which includes the elongated dome of Defiance Plateau, from which Tertiary, Cretaceous, Jurassic, and the larger part of Triassic sediments have been stripped. The western limb of the De Chelly upwarp in many places dips gently beneath the Chinle Valley; elsewhere it drops abruptly westward, forming the Ganado monocline. The eastern limb is sharply downfolded in the Defiance monocline with dips between 20° and 70°. The upturned and eroded edges of strata forming the Defiance monocline may be traced northward from the Santa Fe Railway, along the west front of Manuelito Plateau, until they disappear beneath the Chuska Mountains. Emerging from the base of Chuska Mountain at Toadlena, the monocline continues across Chuska Valley, reaching the San Juan at Hogback Mountain. A minor dome, Todilto Park, interrupts the regularity of the prevailing eastward dip. At the southern border of the reservation the dips of the monocline flatten, and the structure probably disappears some distance beyond Zuni. (See Pl. VIII, *A*, p. 33.)

Eastward from the Defiance monocline an extensive coal field occupies the Gallup syncline, the eastern limb of which is the Nutria monocline, represented by a hogback bordering the Zuni Mountains. North of Manuelito Plateau the Chaco syncline extends to San Juan River.

Black Mesa occupies the center of the Tusayan downwarp, a shallow synclinal structure extending from the Chinle Valley to Echo Cliffs, a distance of nearly 100 miles.

The Echo monocline is crossed by the section shown in Plate XXII a few miles north of Willow Springs. Southward from this point the monocline appears to die out gradually, but northward it extends as a bold escarpment, Echo Cliffs, which crosses Colorado River and continues northward to the west base of Kaiparowitz Plateau.

Along the Little Colorado anticlines with small dips are to be seen at Wolf Crossing and below Grand Falls. Black Point, projecting into Little Colorado River from the west, is a lava-capped monocline, produced by a vertical displacement of "not less than 800 feet."[2]

[1] U. S. Geol. Survey Bull. 471, p. 93, 1911.

[2] Robinson, H. H., The San Franciscan volcanic field: U. S. Geol. Survey Prof. Paper 76, p. 35, 1913.

Along the northern border of Arizona two laccolithic mountains, Carrizo and Navajo, rise high above the surrounding surface. Westward from Carrizo Mountain the strata of the Gothic Mesa form a synclinal basin, the western limb of which is the Comb monocline, which extends as a curved wall from Marsh Pass to and beyond San Juan River. Monument Valley, bisected by San Juan River, is carved from the Monument upwarp, an anticlinal dome, the western limb of which passes downward into the narrow and shallow Oljeto syncline. The eastern wall of Segi Mesas is formed by the Hoskinnini monocline, which gives a rise of 1,200 feet in a distance of about 2 miles.

The structural features outlined above indicate the presence of a series of synclinal basins with long dip slopes, which offer suitable conditions for the storage of artesian water.

GEOLOGIC HISTORY.

The record of pre-Cambrian time within the limits of the Navajo country is exceedingly fragmentary, and is exposed for examination at only one point, namely, Quartzite Canyon, near Fort Defiance. At this locality a mass of quartzite in sharp unconformity with the overlying shales of the Moenkopi formation is revealed by erosion. Where the original bedding is decipherable the mass is seen to consist of coarse sandstone with interspersed lenses of conglomerate. The abundant ripple marks and sun-baked surfaces and the few mud cracks observed suggest subaerial deposition. Since deposition during Carboniferous time was continuous in adjoining areas, it is probable that this mass of quartzite remained as an island through Pennsylvanian and possibly through all earlier Paleozoic time.

During Permian time the land was near sea level and was probably repeatedly submerged to no great depth. The invertebrate fossils so far collected are of marine types, but plant remains are abundant, and many of the beds exhibit subaerial features, and suggest a landscape of little relief exposed to an arid climate.

Conditions prevailing during early Triassic time are unknown, and whether sediments of this age were deposited in the Navajo country is only a matter of speculation. The first recorded deposit of Triassic age is the Shinarump conglomerate, which followed the Permian (?) deposits after a long erosion interval. The coarse siliceous conglomerates of this formation, carrying a large proportion of fossil wood fragments, are probably of subaerial origin. After the Shinarump conglomerate had been laid down the region presented a landscape marked by fresh and brackish water bodies, interlaced with low-lying lands dotted with trees. Arid or semiarid

climates prevailed. This interpretation is based on the composition and structure of the sediments of the Chinle formation and on the evidence of fossils. What part, if any, was taken by the sea remains undetermined.

With increasing aridity and elevation the Navajo country became a desert, with dunes piled high and with restricted and specialized animal and plant life. These conditions probably prevailed during the deposition of strata of the Jurassic La Plata group, the arrangement of which indicates eolian as well as fluviatile deposition. Aridity may have continued throughout Jurassic time, and the lands at this period probably extended over the area included in the Navajo and Hopi reservations. Bodies of water—salt, brackish, and fresh—were present, and were apparently sparsely inhabited by fish and by invertebrates. That sufficient forage and water for animals were available is indicated by the skeletons of dinosaurs embedded in the rocks and by the footprints of those animals discovered in Navajo Canyon and elsewhere. That land at the close of Jurassic time was extensively developed is shown by the widespread erosional unconformity which separates strata provisionally assigned to this age from those of the overlying Cretaceous. This period of vigorous erosion, marked by the unconformity at the base of the Dakota, has removed all traces of deposits laid down during Comanche (Lower Cretaceous) time, if, indeed, any strata of this age were ever present.

At the beginning of Upper Cretaceous time streams were active and portions of the area were represented by water bodies, which were swampy or estuarine in character. The heterogeneous material classed as Dakota sandstone appears to have been laid down mainly by streams. The sea was also present but appears to have confined its activities chiefly to the reworking of sediments previously deposited. For a long period after the deposition of the Dakota sandstone the land was alternately submerged and reelevated, so that shales and sandstones containing marine fossils alternating with beds of lignitic coal were deposited. The series thus formed has been named the Mancos shale. Throughout Mesaverde time also the sea and the land were alternately dominant in northeastern Arizona.

With the coming of the Tertiary the sea is believed to have been permanently excluded from the area included in the Navajo country. Lacustrine deposits containing fresh-water shells tell of the presence of lakes and tangentially cross-bedded sandstones suggest the work of winds. Volcanism was also active during this period and probably continued into the Quaternary. From the beginning of the Tertiary period date the major folds represented in the region and the consequent uplifts which, several times repeated, have

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STRATIGRAPHY.

The sedimentary strata within the limits of the Navajo country are of pre-Cambrian(?), Pennsylvanian, Permian(?), Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary ages. The relations of these systems and series and the formations which they embrace are represented in the generalized section (Pl. XXI).

Pre-Cambrian(?).—Within the area studied the oldest sedimentary formations whose age has been definitely determined are limestones of Carboniferous age. The lower contact of the Carboniferous is not exposed, but at Quartzite Canyon (locally called Blue Canyon) near Fort Defiance, quartzite unconformably underlies strata of Permian(?) age. In composition, structure, and degree of metamorphism this quartzite mass appears to be identical with the pre-Cambrian quartzite of the Colorado Canyon and is believed to be of equivalent age.

Pennsylvanian.—Within the canyon of the San Juan and at Grand Falls and several other points along the Little Colorado strata of buff and brown limestone are well exposed for study, and in the canyon walls this limestone (Kaibab) is underlain by other formations of the Aubrey group. Fossils collected at Goodridge, Utah, in 1909, and on the lower Little Colorado in 1910, taken in connection with later collections by Woodruff, have served to establish the Pennsylvanian age of these beds. The exposed Pennsylvanian strata—the Kaibab limestone and the Goodridge formation—differ materially in lithologic features.

Permian (?).—The beds between the Pennsylvanian limestone and the Shinarump conglomerate are assigned to the Permian (?) on the basis of Walcott's studies in the Kanab Valley and the discovery

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System and series		Formation
QUATERNARY		.
TERTIARY	Eocene (?)	Chuska sandstone
		UNCONFORMITY
		Tohachi shale
		UNCONFORMITY
CRETACEOUS	Upper Cretaceous	Mesaverde and later formations
		Mancos shale
		Dakota sandstone
		UNCONFORMITY
JURASSIC ?		McElmo formation
JURASSIC	La Plata group	Navajo sandstone
		Todilto formation
		Wingate sandstone
		UNCONFORMITY
TRIASSIC		Chinle formation
		UNCONFORMITY
		Shinarump conglomerat
		UNCONFORMITY
CARBONIFEROUS	Permian (?)	De Chelly sandston
		Moenkopi formatio
		UNCONFORMITY
	Pennsylvanian	Aubrey group in Little Colorado River region, and Goodridg formation in San Jua River region (relation unknown)
		UNCONFORMITY
PRE-CAMBRIAN(?)		Quartzite

GENERALIZ

which have such a commanding influence in the plateau region farther west. In fact the fault in Monument Valley,[1] described by Woodruff as having a maximum throw of 200 feet, is the only example of faults exceeding 100 feet in vertical displacement so far known on the reservation. In the eastern part of the district the structural feature of primary importance is the De Chelly upwarp, which includes the elongated dome of Defiance Plateau, from which Tertiary, Cretaceous, Jurassic, and the larger part of Triassic sediments have been stripped. The western limb of the De Chelly upwarp in many places dips gently beneath the Chinle Valley; elsewhere it drops abruptly westward, forming the Ganado monocline. The eastern limb is sharply downfolded in the Defiance monocline with dips between 20° and 70°. The upturned and eroded edges of strata forming the Defiance monocline may be traced northward from the Santa Fe Railway, along the west front of Manuelito Plateau, until they disappear beneath the Chuska Mountains. Emerging from the base of Chuska Mountain at Toadlena, the monocline continues across Chuska Valley, reaching the San Juan at Hogback Mountain. A minor dome, Todilto Park, interrupts the regularity of the prevailing eastward dip. At the southern border of the reservation the dips of the monocline flatten, and the structure probably disappears some distance beyond Zuni. (See Pl. VIII, *A*, p. 33.)

Eastward from the Defiance monocline an extensive coal field occupies the Gallup syncline, the eastern limb of which is the Nutria monocline, represented by a hogback bordering the Zuni Mountains. North of Manuelito Plateau the Chaco syncline extends to San Juan River.

Black Mesa occupies the center of the Tusayan downwarp, a shallow synclinal structure extending from the Chinle Valley to Echo Cliffs, a distance of nearly 100 miles.

The Echo monocline is crossed by the section shown in Plate XXII a few miles north of Willow Springs. Southward from this point the monocline appears to die out gradually, but northward it extends as a bold escarpment, Echo Cliffs, which crosses Colorado River and continues northward to the west base of Kaiparowitz Plateau.

Along the Little Colorado anticlines with small dips are to be seen at Wolf Crossing and below Grand Falls. Black Point, projecting into Little Colorado River from the west, is a lava-capped monocline, produced by a vertical displacement of "not less than 800 feet."[2]

[1] U. S. Geol. Survey Bull. 471, p. 93, 1911.

[2] Robinson, H. H., The San Franciscan volcanic field: U. S. Geol. Survey Prof. Paper 76, p. 35, 1913.

Along the northern border of Arizona two laccolithic mountains, Carrizo and Navajo, rise high above the surrounding surface. Westward from Carrizo Mountain the strata of the Gothic Mesa form a synclinal basin, the western limb of which is the Comb monocline, which extends as a curved wall from Marsh Pass to and beyond San Juan River. Monument Valley, bisected by San Juan River, is carved from the Monument upwarp, an anticlinal dome, the western limb of which passes downward into the narrow and shallow Oljeto syncline. The eastern wall of Segi Mesas is formed by the Hoskinnini monocline, which gives a rise of 1,200 feet in a distance of about 2 miles.

The structural features outlined above indicate the presence of a series of synclinal basins with long dip slopes, which offer suitable conditions for the storage of artesian water.

GEOLOGIC HISTORY.

The record of pre-Cambrian time within the limits of the Navajo country is exceedingly fragmentary, and is exposed for examination at only one point, namely, Quartzite Canyon, near Fort Defiance. At this locality a mass of quartzite in sharp unconformity with the overlying shales of the Moenkopi formation is revealed by erosion. Where the original bedding is decipherable the mass is seen to consist of coarse sandstone with interspersed lenses of conglomerate. The abundant ripple marks and sun-baked surfaces and the few mud cracks observed suggest subaerial deposition. Since deposition during Carboniferous time was continuous in adjoining areas, it is probable that this mass of quartzite remained as an island through Pennsylvanian and possibly through all earlier Paleozoic time.

During Permian time the land was near sea level and was probably repeatedly submerged to no great depth. The invertebrate fossils so far collected are of marine types, but plant remains are abundant, and many of the beds exhibit subaerial features, and suggest a landscape of little relief exposed to an arid climate.

Conditions prevailing during early Triassic time are unknown, and whether sediments of this age were deposited in the Navajo country is only a matter of speculation. The first recorded deposit of Triassic age is the Shinarump conglomerate, which followed the Permian (?) deposits after a long erosion interval. The coarse siliceous conglomerates of this formation, carrying a large proportion of fossil wood fragments, are probably of subaerial origin. After the Shinarump conglomerate had been laid down the region presented a landscape marked by fresh and brackish water bodies, interlaced with low-lying lands dotted with trees. Arid or semiarid

climates prevailed. This interpretation is based on the composition and structure of the sediments of the Chinle formation and on the evidence of fossils. What part, if any, was taken by the sea remains undetermined.

With increasing aridity and elevation the Navajo country became a desert, with dunes piled high and with restricted and specialized animal and plant life. These conditions probably prevailed during the deposition of strata of the Jurassic La Plata group, the arrangement of which indicates eolian as well as fluviatile deposition. Aridity may have continued throughout Jurassic time, and the lands at this period probably extended over the area included in the Navajo and Hopi reservations. Bodies of water—salt, brackish, and fresh—were present, and were apparently sparsely inhabited by fish and by invertebrates. That sufficient forage and water for animals were available is indicated by the skeletons of dinosaurs embedded in the rocks and by the footprints of those animals discovered in Navajo Canyon and elsewhere. That land at the close of Jurassic time was extensively developed is shown by the widespread erosional unconformity which separates strata provisionally assigned to this age from those of the overlying Cretaceous. This period of vigorous erosion, marked by the unconformity at the base of the Dakota, has removed all traces of deposits laid down during Comanche (Lower Cretaceous) time, if, indeed, any strata of this age were ever present.

At the beginning of Upper Cretaceous time streams were active and portions of the area were represented by water bodies, which were swampy or estuarine in character. The heterogeneous material classed as Dakota sandstone appears to have been laid down mainly by streams. The sea was also present but appears to have confined its activities chiefly to the reworking of sediments previously deposited. For a long period after the deposition of the Dakota sandstone the land was alternately submerged and reelevated, so that shales and sandstones containing marine fossils alternating with beds of lignitic coal were deposited. The series thus formed has been named the Mancos shale. Throughout Mesaverde time also the sea and the land were alternately dominant in northeastern Arizona.

With the coming of the Tertiary the sea is believed to have been permanently excluded from the area included in the Navajo country. Lacustrine deposits containing fresh-water shells tell of the presence of lakes and tangentially cross-bedded sandstones suggest the work of winds. Volcanism was also active during this period and probably continued into the Quaternary. From the beginning of the Tertiary period date the major folds represented in the region and the consequent uplifts which, several times repeated, have

brought the land to its present position with respect to the sea. At one stage during late Tertiary time (Pliocene) erosion became dominant and reduced parts of the area to a peneplain. The gradient of the streams was later increased by a regional uplift, which enabled them greatly to reduce the area occupied by Mesozoic and Cenozoic strata. Other uplifts, amounting to 3,000 to 4,000 feet, still further augmented the power of the streams and enabled them to cut the canyons which form so conspicuous a feature of Navajo topography.

PART II. SURFACE WATERS.

STREAMS.

MASTER STREAMS OF THE REGION.

Three large rivers—the Colorado, the San Juan, and the Little Colorado, with its tributary, the Puerco—mark the borders of the Navajo country. The Colorado, the master stream of the plateau province, eventually receives the surface water from the entire region except for an insignificant amount carried to the Rio Grande. From the mouth of the San Juan to Echo Cliffs the Colorado flows between the brightly colored walls of Glen Canyon; below Lee Ferry it occupies the still more profound Marble Canyon. Throughout its course in the Navajo country it flows as a powerful stream whose moderate grade is interrupted by few rapids.

The San Juan is a perennial stream. Along its upper course it receives the waters of vigorous tributaries which have their sources in the San Juan and La Plata mountains. Within the 90-mile stretch of winding channel from Bluff to Colorado River it receives no continuous supply of importance, but maintains a depth of 3 to 5 feet even in the dry season.[1] Measurements of flow taken at Farmington, N. Mex., gave the following results:

Monthly discharge, in second-feet, of San Juan River at Farmington, N. Mex.[a]

Month.	Maximum.	Minimum.	Mean.
1904.			
June (12 days)	1,300	780	1,030
July	1,578	20	375
August	4,980	1,450	2,627
September	8,625	400	1,375
October	20,000	2,625	5,935
November	1,695	630	1,087
December	780	90	348
1905.			
January	338	40	242
February	2,582	230	682
March	3,410	780	1,625
April	7,460	1,085	4,290
May	19,100	4,635	10,110
June	24,800	10,960	18,270
July	8,240	2,180	3,604
August	3,740	840	1,747
September	4,870	1,180	1,673
October	4,635	1,180	1,690
November	2,708	1,085	1,306
December	1,300	840	1,084
1906.			
May			11,700
June 4			9,090
June 8 (station discontinued)			12,800

[a] U. S. Geol. Survey Water-Supply Paper 133, pp. 180-183, 1904; Water-Supply Paper 175, p. 134, 1906; Water-Supply Paper 211, p. 101, 1908.

[1] The course of the San Juan below Bluff, as shown on published maps, is correct only with respect to general direction.

The Puerco-Little Colorado is an intermittent stream. From its source on the Continental Divide in New Mexico to Holbrook in Arizona it is marked at low water by a dry bed interrupted by stretches of stream rarely exceeding a mile in length. I have been informed that during parts of certain years no flowing water is to be found in the Puerco from Gallup westward to its mouth. At Holbrook it joins the upper Little Colorado, a perennial stream from the White Mountains. Between Hardy and Winslow the Little Colorado receives the waters of Chevelon Fork and Clear Creek,[1] tributaries from the central Arizona highlands which give to the Little Colorado its perennial character throughout the 33-mile course from Holbrook to Winslow and make this section, including the settlements at Holbrook, St. Joseph, and Winslow the only part of the Puerco-Little Colorado Valley that has attained commercial importance. From Winslow to Colorado River, a distance of over 100 miles, the flow of the Little Colorado is seasonal, and during years of normal precipitation it reaches a stage where no running water is to be found except on the floor of the canyon near the junction with its master stream. The quantity of water it carries at Holbrook, where its continuous flow is largest, is given in the following table:

Monthly discharge, in second-feet, of Little Colorado River at Holbrook, Ariz.[a]

Month.	Maximum.	Minimum.	Mean.
1905.			
March (15 days)	1,190	718	863
April	2,075	504	915
May (25 days)	1,055	145	353
June	145	44	82.6
July	488	5	67.9
August	1,200	33	163
September	1,760	15	302
October	220	19	50.7
November	20,180	30	1,159
December	325	45	113
1906.			
January	1,330	165	452
February	325	73	170
March	3,540	66	621
April	987	100	245
May	150	5	54
June	5	3	4.1
July	140	3	24.9
August	275	15	71.5
September	600	4	68.7
October	250	5	26.6
November	63	4	11.3
December	890	25	181
1907.			
January	1,000	90	276
February	380	73	176
March	2,100	115	444
April	573	290	401

[a] U. S. Geol. Survey Water-Supply Paper 133, pp. 180–183, 1904; Water-Supply Paper 175, p. 134, 1906; Water-Supply Paper 211, p. 101, 1908.

[1] In 1906 the maximum flow of Chevelon Fork near Winslow was 3,870 second-feet (in March), the minimum was 0.25 second-foot (September to November), and the mean for the year was 110 second-feet; from June 3 to December 31 of the same year the maximum discharge of Clear Creek near Winslow was 2,245 second-feet (in December), and the minimum was 3 second-feet (in August): U. S. Geol. Survey Water-Supply Paper 211, pp. 117, 119, 1908. The mean discharge of Clear Creek for the period has been computed as 52.9 second-feet.

THROUGH-FLOWING STREAMS.

The Colorado, the San Juan, and the Little Colorado are the only streams of the Navajo country that carry water from areas beyond the limits of the reservation. Within the reservation the drainage from 9,897 square miles, an area which contains no perennial through-flowing streams, is directed toward the Puerco and Little Colorado. The Colorado receives the waters from Navajo Creek, a perennial stream through the 54 miles of its canyoned course and carrying at low stages nearly 2 second-feet of water. Several of the short, deep canyons entering the Colorado from the Rainbow Plateau contain minute streams; Oak Creek and Nasja furnish perennial supplies; and a rill of clear, pure water finds its way down Bridge Canyon, passing beneath the Rainbow Arch. The San Juan is the goal of Junction, Cha, and Desha creeks, which drain the northern slopes of Navajo Mountain and maintain a flow of 10 to 100 gallons a minute, even during the season when precipitation is lacking and evaporation assumes excessive proportions.

The San Juan also receives perennial supplies from Piute Creek, which drains a narrow strip of land immediately adjoining its canyoned valley. (See Pl. XVIII, *A*, p. 69.) In July, 1910, the estimated flow of Piute Creek 6 miles above its mouth was 0.20 second-foot, and the average of two estimates made in June, 1913, at points near the head of the canyon was 0.15 second-foot. Nokai, Copper, and Moonlight canyons hold trickling rills of water which find their way into the San Juan. Gypsum Creek, which drains the eastern half of Monument Valley, is rarely dry. The longest stream of perennial flow which finds its way to the borders of the reservation is Tyende Creek. This stream emerges from the many-branched Laguna Canyon at Marsh Pass, winds its way through the hogback rim of Monument Valley, traverses Sahotsoidbeazhe Canyon, and enters Chinle Valley, which it follows to the San Juan. At Marsh Pass the discharge during the dry season is about 1.70 second-feet, which is the largest flow noted at any point along the stream during the months of June and July, 1909, 1910, and 1913.

INTERMITTENT STREAMS.

Within the limits of the reservation are a number of intermittent streams that occupy well-defined drainage channels but reach their master streams only during the rainy season. Three of these streams, the Moenkopi, Black Creek, and the Pueblo Colorado, are tributary to the Puerco and Little Colorado.

MOENKOPI CREEK.

Of all the tributaries of the lower Little Colorado the Moenkopi (Hopi, running water) flows most continuously and responds most

readily to seasonal precipitation. Topographically it is separable into three sections of subequal length. The upper third (25 miles) is intrenched in the Cretaceous strata of Black Mesa, forming a narrow, steep-walled canyon, joined by tributaries that occupy valleys of similar shape. The terraces and flats on the canyon floor are a few acres in extent and are discontinuous. The stream is fed during the dry season by a few springs and seeps distributed along its course, which supply an interrupted flow of 10 to 30 gallons a minute. At Blue Canyon (Navajo, Bokogo dotklish) the intermittent stream emerges from the dark-gray rocks of the upper canyon and enters the second part of its course, where it is confined between low walls of brilliantly colored sandstones of Jurassic age. During this stretch of 30 miles, between Blue Canyon and the cliffs west of Tuba, the stream is alternately buried by sand and brought to the surface by ledges of rock. Patches of alluvium, 10 to 50 acres in extent, flanking the stream channel, from time to time have been reclaimed by irrigation, occasionally at considerable expense. Near Moenkopi village the underflow of the stream is brought to the surface by exposed rock ledges and is supplemented by supplies from Reservoir Canyon and from numerous springs of the vicinity. The combined flow of water from these sources amounts, even in dry seasons, to perhaps 5 second-feet and exceeds that at any other locality on the reservation. Fortunately wide valley flats below Moenkopi village are favorably situated for irrigation, and agriculture has here reached a higher stage of development than elsewhere in the Navajo country. The Spanish pioneers found at Moenkopi cultivated fields of corn and of cotton, and the Mormon settlers of the Tuba oasis used these same fields for corn, wheat, oats, and alfalfa. Under the direction of the Indian Office, Hopi, Navajo, and white men now work side by side in cultivating this garden spot surrounded by an inhospitable desert.

The lower part of the Moenkopi wanders for 20 miles through the Painted Desert to join the canyon of the Little Colorado. Throughout this stretch of subdued topography its flow is intermittent and the Triassic shales which form its bed yield alkali which renders the water unpalatable.

BLACK CREEK.

From its source in Chuska Mountain to Red Lake the waters of Black Creek are in view except for stretches of a fraction of a mile. Swamps and seeps mark the sources of the various branches, and flat valley floors, susceptible of irrigation, line the stream for several miles. The run-off from 230 square miles, constituting the drainage area of this portion of Black Creek, including Red Lake, was found by the engineers of the Indian Service to be 33,328 acre-feet a year. From Red Lake to St. Michaels Black Creek occupies a shallow arroyo cut in the floor of a wide, flat-bottomed valley. Within this

distance water is present even in the dry season, as short stream stretches, interrupted by expanses of dry sandy floor. The stream is also intermittent along its course from St. Michaels to Oak Spring, below which it becomes perennial while passing through lower Black Creek Canyon, assuming once more an intermittent character in the 10-mile stretch ending at Puerco River. Two short tributaries to Black Creek, one from Buell Park, the other at St. Michaels, are perennial for a mile or so of their upper courses and reach their master stream for about six months in a year. A third tributary, Bonito Creek, rising in Quartzite Canyon, discharges at low water 0.87 second-foot,[1] and though only about 5 miles long has determined the location of Fort Defiance and made possible the irrigated fields and gardens which give to this spot its attractive features.

PUEBLO COLORADO WASH.

Nearly 1,250 square miles of the Defiance Plateau is drained by the Pueblo Colorado Wash, the upper 18 miles of which, from its source to Ganado, is a perennial stream, its discharge at low water being perhaps 2 second-feet. (See p. 110.) From Ganado to Holbrook, a distance of more than 100 miles, the stream flows only in response to showers. The terraces along the canyon in the upper portion and the wide flats below the mouth of the canyon have been cultivated by means of irrigation since the days of the cliff dwellers, and this permanent supply of water in the midst of an arid expanse has made of Ganado an important center of agricultural and commercial activity for the Navajos and the white traders.

CHINLE DRAINAGE SYSTEM.

The 4,790 square miles of the Navajo Reservation included in the Chinle drainage area comprises a region intimately associated with the life of the Navajo race and with the history of the prehistoric populations of the plateau province. Cliff ruins are found in nearly all the canyoned tributaries and traces of ancient irrigated fields are distributed far and wide through the valleys. Following the cliff dweller and the Hopi, the Navajo has occupied the favorable spots within the Chinle basin and practiced agriculture by irrigation and dry farming, making use of his knowledge of fluctuation in stream flow. The main Chinle is ephemeral in its flow from its head, 6 miles northwest of Ganado, to Chinle, a distance of 38 miles. From Chinle to the mouth of Tyende Creek the stream is ephemeral or in rare years intermittent during the dry season, with the proportion of waterless bed much in excess of flowing stretches. Below the mouth of the Tyende the flow of the Chinle is permanent, except where obstructed for short distances by accumulations of wind-

[1] Measured by Lieut. H. C. Brown, October, 1892.

blown sand. Above the Tyende the western tributaries of the Chinle contain no perennial waters except for stretches usually less than a mile in length immediately below the springs which supply them. Some of these short streams have their origin in the Mancos shale or Chinle formation, and contain an amount of salts which renders their waters unfit for domestic uses. From the east the Chinle receives the drainage from Nazlini Canyon, Canyon de Chelly, Canyon del Muerto, Lukachukai Valley, and Walker Creek valley—channels whose upper parts, at least, are occupied by perennial streams. The Nazlini, at the exit from its canyon, has, in the dry season, a small permanent discharge, which decreases downstream until the flow becomes intermittent and finally disappears. The De Chelly is fed by small perennial streams—Whiskey Creek, Palisade Creek, and Wheatfields Creek—which rise in the Chuska Mountains and furnish Canyon de Chelly with a supply of water that is augmented by springs distributed along its course. Where measured, 6 miles from its mouth, the De Chelly, in May, 1909, had an estimated flow of 0.60 second-foot.

Canyon del Muerto is the lower part of Spruce Brook, which emerges from Tunitcha Mountain as a clear stream of pure water with a discharge exceeding 1 second-foot. Spruce Brook drops into Canyon del Muerto at Sehili,[1] and continues with more or less interrupted flow to its junction with Canyon de Chelly. Along the lower reaches of Whiskey, Palisade, and Wheatfields creeks and Spruce Brook, the flats adjoining the streams are favorably situated for irrigation. Below the mouth of Canyon del Muerto the De Chelly is normally without flowing water during the dry season.

Lukachukai Creek forms the division line between the Tunitcha and Lukachukai mountains. From its source at the crest of the mountains to the Lukachukai settlement, at the mountain base, the stream occupies a narrow wooded valley and carries even in the dry season 2 or 3 second-feet of water. For 6 or 8 miles below Lukachukai the creek maintains a perennial flow but assumes an intermittent character in the vicinity of Round Rock. Below this point the bed is normally dry for a few months each year. The colony of enterprising Navajos at Lukachukai make use of the waters of this stream to irrigate about 200 acres of corn, alfalfa, and garden lands.

The west side of Carrizo Mountain is drained by Walker Creek.[2] The upper portion of the stream, emerging from the narrow, steep-

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[1] Sehili in the Navajo language means the place where water disappears into a canyon; Chinle, the place where water emerges from a canyon mouth.

[2] In the absence of a recognized name for this stream the liberty is taken of naming it Walker Creek in honor of Capt. Walker, of Macomb's expedition of 1859. Capt. Walker crossed the stream at Ojo de Casa (Navajo: Hogan sa-a-ni, lone house in the desert). The term Gothic Wash, used on many maps, is discarded, as this name was given by Macomb to a dry canyon entering the San Juan below Bluff. See map accompanying report on the exploring expedition, etc., in 1859, under the command of Capt. J. N. Macomb, Eng. Dept., U. S. Army, Washington, 1876.

floored canyon, is called by the Navajos Chinlini (place where water comes out of a canyon); the lower middle portion is sometimes spoken of as Mexican Water, a name still retained for the store at the point where the Mormon Road of 1879 crossed the creek. Walker Creek is perennial, except for widely separated short stretches. After leaving its upper canyon at Chinlini the stream occupies a trench cut in the alluvial floor of a rock-walled canyon and in many places rests on rock. Near its junction with the Chinle the canyon is wide and the stream finds its way with more or less interrupted flow between terraces which indicate the level of a previous stage of water. The flow of Walker Creek at Chinlini as estimated is 0.70 second-foot, and I am informed that at the Mexican Water store the discharge during the summer season is about 500 gallons a minute.

In addition to the streams mentioned, two short creeks, Sheep Dip, about 12 miles north of Chinle School, and Agua Sal, entering Lukachukai Creek north of Round Rock, flow intermittently toward their master streams. The water of Sheep Dip Creek is palatable, but that of Agua Sal is said to be unfit for general use.

To the Chinle system belongs also Simpson Creek, which rises in the meadows as Washington Pass and crosses the New Mexico-Arizona boundary line near Crystal, on its way to Black Lake. The New Mexico portion of the stream is perennial and increases the attractiveness of the Washington Pass route from Fort Defiance to the San Juan. Before reaching Black Lake, however, Simpson Creek becomes intermittent and the extreme lower part flows during the dry season only in response to showers.

STREAMS TRIBUTARY TO CHUSKA VALLEY.

On the eastern flanks of the Chuska Mountains are a number of short, perennial, or intermittent streams which occupy the upper portions of canyoned valleys whose ultimate goal is the poorly defined drainage system of the Chuska Valley. The southernmost of these streams, Figueredo Creek, crossed by the Fort Defiance-Tohachi Road, is perennial for about 5 miles of its course, with a volume in dry seasons of about 30 gallons a minute. In the gap west of Chuska Peak another small stream of permanent flow was noted, and along the rim of Chuska Mountain, between Tohachi and Washington Pass, are several rills, each less than a mile long, which represent the overflow from springs. At Washington Pass a brook 2 miles or more in length discharges 20 to 25 gallons a minute through all seasons. At Toadlena is another short brook, and in the wide amphitheater south of Beautiful Mountain short streams with permanent or intermittent flows emerge from the plexus of profound canyons which gash the east face of Tunitcha Mountain. The

largest of these, Tseanazti Creek, has long been used for irrigation by cliff dweller and Navajo. Toward the Chuska Valley are directed also several short intermittent streams which rise on the northwest front of Dutton Plateau. Five visited by my party were all more or less alkaline, but not to an extent which rendered them useless for watering sheep. Selukai Creek, on which is located the Government sheep dip, is usually dry except during the rainy season.

ADDITIONAL STREAMS.

In the canyons of Redrock Valley short streams of intermittent flow were found to furnish sufficient supplies for camp and for wandering bands of sheep. Eleven valleys on the slopes of Carrizo Mountain hold in their upper courses tiny rills of perennial flow. Only three of these—Walker Creek, Biltabito, and Tisnasbas—flow continuously from the top to the base of the mountain during the dry season, and the discharge from the largest of these streams, Tisnasbas, was found by Dr. Emery, in July, 1913, to be 0.20 second-foot. On Black Mesa one permanent stream was observed, in addition to several short trickling rills, the outflow from springs. This stream, the Tahchito, maintains a flow of 20 to 30 gallons a minute for a distance of about 5 miles.

DRAINAGE OBSTRUCTED BY DUNES.

Valleys trending southwest from Shato Plateau furnish a resting place for the wind-blown sand stripped from the surface of Kaibito Plateau, and the streams in the valleys are accordingly blocked from place to place. After rains Shato and Begashibito brooks are merely a series of lakes and pools tied together by streams. During the dry season the valley axis resembles a string of beads and the flow of the stream is so completely interrupted that lakes bordered by vegetation are separated from one another by stretches of dry floor heaped with dunes.

EPHEMERAL STREAMS.[1]

The through-flowing and intermittent streams described above traverse less than 1 per cent of the linear extent of drainage channels in the Navajo country. During the dry season the ratio of valleys occupied by streams to valleys without water is, for channels exceeding 25 miles in length, about 1:100, and for channels between 5 and 10 miles in length about 1:340. Except during the rainy season the area drained by perennial surface waters is perhaps less than 5 per cent of the 25,725 square miles constituting the area under

[1] On the map (Pl. I) ephemeral streams are not separately indicated. The longer ones are included with "intermittent" streams; most of them are not shown.

discussion. No permanent stream, except the Moenkopi, was found west of the Chinle Valley and south of latitude 36° 14′, a district constituting about one-half of the reservation. The Kaibito Plateau and a large part of the Gothic Mesas are also without perennial drainage.

With the coming of the rains conditions are radically modified and the dry valley floors are covered with rivers and tributary brooks. A single shower may convert any one of a score of intermittent rills into a through-flowing stream, and raise a group of dry washes to the dignity of rivers. During the season of daily rains, the last part of July and August, the aspect of the country is entirely changed. The Chinle system becomes integrated, and tributaries of the third and fourth degree contribute their daily supply. During this period the forbidding dry, hot valleys leading to the Little Colorado are transformed into a series of silt-laden rivers exceeding 100 miles in length, and the Little Colorado itself becomes a river of commanding proportions, ranking with the Gila and the San Juan in the volume of water carried to the Colorado. Throughout the extent of the Navajo country the ephemeral or seasonal stream is the prevailing type, and all studies relating to the development of water resources in the Colorado Plateau province should include this factor of primary importance.

SUMMARY TABLE OF STREAMS.

The drainage area, length, and type of stream on the reservation are indicated in the following table. Distances and areas and the relation of tributaries to master streams are based on the reconnaissance topographic maps of the United States Geological Survey; statements regarding the characteristics of the streams are taken from field notes, supplemented by information supplied by Navajos, Indian traders, and Government officers.

Principal streams of the Navajo country.

Name.	Drainage area.	Length.	Type.	Character of water.
	Sq. miles.	*Miles.*		
Puerco and Little Colorado.	9,897	252		Heavily silt laden except at low water.
Puerco River	1,326	97	Intermittent	
Black Creek	272	61	Perennial 16 miles at head; perennial for 6 miles below Oak Spring; remainder intermittent.	Clear, fresh.
Bonito Creek	38.5	4	Perennial	
Lithodendron Creek	156	28	Ephemeral	
Little Colorado below junction with Puerco.	8,571.5	156	Perennial between Holbrook and Winslow; intermittent for 5 miles below Winslow; ephemeral 92 miles.	Muddy except at extremely low water; slightly alkaline and salty.
Leroux Wash	203.5	23	Ephemeral	
Pueblo Colorado Wash.	1,247	56	Intermittent 10 miles at upper end; perennial for 8 miles above Ganado; ephemeral from Ganado to mouth.	

Principal streams of the Navajo country—Continued.

Name.	Drainage area.	Length.	Type.	Character of water.
	Sq. miles.	*Miles.*		
Wide Ruin Wash	445	38	Ephemeral	
Cottonwood Wash	527.5	58	....do	
Corn Creek (from Tolani Lakes to mouth).	49	13	....do	
Coyote Wash	338.5	28	....do	
Jadito Wash	623	50	....do	
First Mesa Wash	672.5	56	....do	
Wepo Wash	179	21	....do	
Second Mesa Wash	67	30	....do	
Oraibi Wash	652	85	....do	
Dinnebito Wash	872	100	....do	
Moenkopi Creek, not including Red Lake Valley drainage.	969	76	Perennial 35 miles; intermittent 18 miles; ephemeral 23 miles.	
Moenkopi Wash (Tuba to mouth).	367	20	Perennial except for short stretches	Alkaline.
Red Lake and Klethla valleys.	312	46	Ephemeral except at lower end	
Colorado River drainage	1,877	162	Perennial	Heavily silt laden.
Navajo Creek	770	54	....do	Clear, fresh, except in flood seasons.
Bridge Creek	23	7	....do	Clear, fresh.
San Juan River drainage (San Juan River below Farmington).	13,951	220	....do	Silt laden except at low water.
Piute Creek	285	35	....do	Fresh, clear, except in flood seasons.
Nokai Creek [a]	246	34	....do	Do.
Copper Creek [a]	26	14	....do	Fresh, clear.
Moonlight Creek (including Segihatsosi drainage).	477	42	Perennial 4 miles; intermittent 18 miles; ephemeral 20 miles.	Clear, fresh, in upper portions.
Gypsum Creek	169	30	Perennial, lower portion	Alkaline; unpalatable.
Chinle Creek (or wash).	4,790	104	Ephemeral 86 miles; intermittent 18 miles.	Silt laden except at lowest stages.
Walker Creek	387	38	Perennial	Clear, fresh.
Tyende Creek	975	62	....do	Do.
Lukachukai Creek	325	30	Perennial 10 miles; intermittent 14 miles.	Clear, fresh from source to Round Rock; slightly alkaline below.
Agua Sal Creek	103.5	24	Ephemeral 6 miles; intermittent 8 miles; ephemeral 16 miles.	Reported to be alkaline.
Canyon de Chelly Creek	162.5	20	Perennial 15 miles; intermittent lower 5 miles.	Fresh, clear, except in flood.
Spruce Brook	73	18	Perennial	Clear, fresh.
Canyon del Muerto Creek	107.5	17	Intermittent	Do.
Wheatfields Creek	87	16	Perennial	Do.
Palisade Creek	16	8	....do	Do.
Whiskey Creek	49	9	....do	Do.
Simpson Creek	80.5	12	Perennial 10 miles; ephemeral 2 miles.	Fresh, clear, except lower 4 miles.
Monument Creek	100	16	Intermittent	Fresh, clear.
Nazlini Creek	243	24	Perennial 9 miles; intermittent 3 miles; ephemeral 12 miles.	Fresh, clear, in canyoned portion.
Beautiful Valley Wash	155	28	Ephemeral	
Gothic Wash	197	25	....do	
Desert Creek	87	15	....do	
Arido Creek	166	25	Ephemeral or intermittent	
Tisnasbas Creek	73.5	18	Perennial 6 miles; intermittent 2 miles; ephemeral 10 miles.	Fresh, clear, in upper portion.
Biltabito Creek	64	15	Perennial 3 miles; intermittent 4 miles; ephemeral 8 miles.	Fresh, clear, in perennial portion.
Red Wash	521	30	Intermittent; ephemeral	Slightly alkaline except at head tributaries.
Standing Redrock Creek.	67	13	Perennial 9 miles; intermittent 2 miles; ephemeral 2 miles.	Clear, fresh.
Blackhorse Creek	46	12	Perennial 3 miles; intermittent 9 miles.	Do.
Rio Chaco	4,791	82	Ephemeral with intermittent stretches.	

[a] The area drained and the length of Nokai Creek are rough approximations only. The topography of this area as shown on the Marsh Pass and Henry Mountains maps gives an erroneous idea of the drainage relations of Copper, Nokai, and Piute canyons.

FACTORS INFLUENCING STREAM FLOW.

PRECIPITATION.

AMOUNT.

With the exception of the San Juan, the Colorado, and the Little Colorado, the streams of the Navajo country are fed by water that falls within its borders. The annual mean precipitation has been determined at a few points (see pp. 50–59) and found to be small in amount and to vary widely at different localities. The records for Fort Defiance and St. Michaels, at elevations of about 6,900 feet, giving a mean annual fall of 12.80 inches, represent fairly the combined rainfall and snowfall for Defiance Plateau, Black Creek Valley, Manuelito Plateau, and Dutton Plateau, are doubtless somewhat too low for the Chuska Mountains and Carrizo Mountain and are probably slightly too high for Black Mesa.

The mean annual precipitation of 10.62 inches at Chinle (elevation about 6,400 feet) is probably higher than for Chinle Valley as a whole, as well as for Monument Valley and the Gothic Mesas. The average annual precipitation at Holbrook is 9.15 inches. It may be noted that evaporation at Holbrook during this same period averaged 46.32 inches, that is, more than five times the amount of rainfall. These figures may reasonably be extended to cover the Hopi Buttes, the Tusayan Washes, and the upper Puerco and Little Colorado Valley.

The area centering at Tuba is the most arid part of the Navajo country. The records of rainfall at this station give an average precipitation of 5.30 inches, a figure that may be extended to cover the Kaibito Plateau, and possibly also the Moenkopi Plateau and a large part of the Rainbow Plateau. Judging from the vegetation, Shato Plateau and Segi Mesas receive 20 to 30 per cent more rain than is recorded at Tuba. On the other hand the precipitation in the Painted Desert below Grand Falls probably reaches, on the average, less than 3 inches, and in some years the total rainfall has been insufficient to produce run-off. On one occasion, according to reports of a Navajo headman, two years in succession were marked by the absence of rain at Tanner Crossing.

Navajo Mountain, which rises 4,000 feet above its plateau base, is visited by rainclouds which pass unchanged across the lower lands to the west and probably receives precipitation, including snow, of more than 20 inches, sufficient to support a relatively luxuriant vegetable cover. A mean annual precipitation of 6.92 inches at Hite, Utah, 40 miles north of the mouth of San Juan River, may be taken as representative of the immediate valley of Colorado River from Lee Ferry to the mouth of Fremont River. The rainfall along the middle and upper San Juan Valley is fairly repre-

sented by the records at Aneth, which give a mean annual precipitation of 4.96 inches, and at Fruitland, which receives on the average 6.89 inches of rain a year.

Carrizo Mountain, like Navajo Mountain, rises as a solitary mass to a height of 9,420 feet, and receives probably more than twice the rain that falls in San Juan Valley at its base.

DISTRIBUTION IN TIME.

The average of the means of annual precipitation for Fort Defiance and St. Michaels, Keams Canyon, Holbrook, Winslow, Tuba, Chinle, Aneth, Fruitland, and Hite is 8.29 inches, a figure which, for present purposes, may be considered as the annual rainfall for the Navajo country as a whole. It will be readily understood that this amount is scarcely sufficient to maintain permanent flow even if the rain were evenly distributed throughout the year and from year to year, thus giving a mean monthly precipitation of about 0.62 inch. Any opportunity, however, which the rainfall might otherwise have of furnishing the watercourses with continuous small flows is offset by the nature of the precipitation in which the following elements are dominant.

VARIATION THROUGHOUT THE YEAR.

When records for all stations are compared, it appears that the rainfall of the reservation is characterized by a maximum during July, August, and September and a minimum during April, May, and June. January and February and, to a less degree, December are months in which a small amount of rain is to be expected; October and November are nearly always dry. The seasonal variation at Holbrook is as follows: Spring, 1.41 inches; summer, 3.32 inches; autumn, 2.41 inches; and winter, 2.01 inches. In descending order of the amount of rainfall at Holbrook the months may be arranged as follows: July, August, November, September, January, October, February, March, December, April, May, and June. The figures for Keams Canyon are: Spring, 1.76 inches; summer, 3.77 inches; autumn, 2.28 inches; winter, 3.13 inches. July and August are the wettest months, followed in turn by December, March, October, February, January, September, November, April, June, and May. Chinle receives 2.29 inches of rain during the winter, 1.25 inches in the spring, 4.31 in summer, and 2.77 in the autumn. The greatest precipitation occurs during July, that of August, December, September, October, March, February, April, June, November, January, and May following in descending order.

The fact that the months group themselves naturally into wet and dry seasons results in a higher percentage of run-off for the Navajo country than if rain were evenly distributed throughout the

year. During periods of concentrated rainfall evaporation is lessened and the amount of water absorbed by the ground is decreased. Slight continuous precipitation at intervals favors the maximum accumulation of ground water and consequent decrease in amount of run-off.

VARIATION FROM YEAR TO YEAR.

Dry years and relatively wet years are indicated by the records of stations in the Navajo country, and great inequalities in the monthly precipitation from year to year are also noticeable. (See discussion under "Climate," pp. 60–61.) The run-off increases with an increase in the amount of precipitation, but is not directly proportional to the rainfall. In fact, the difference between maximum and minimum run-off may exceed the difference between maximum and minimum of mean annual precipitation by several hundred per cent.

VIOLENT SHOWERS OF SHORT DURATION.

The rain in the Navajo country falls in violent showers, which may last a few hours or only a few minutes. Rains that fall as gentle downpours and continue for a day or more are rare. Thundershowers during which clouds gather, rain falls, and the sky again clears, all within the space of half an hour or less, are typical.

Snow falls in winter at all elevations above 5,000 feet and in some years at lower elevations. Hailstorms are not uncommon.

Sudden heavy showers tend to increase the proportion of the total rainfall that is carried away by streams. An inch or so of the ground may become saturated during the first few minutes of such storms and the water which later falls may nearly all form part of the run-off. (See p. 63.)

EVAPORATION.

The mean annual temperature for the coldest station on the Navajo Reservation proper, namely, Fort Defiance, is 47.6°, the winter mean being 28.6°, and the summer mean 66°. For Holbrook the figures are annual mean 54.2°, winter mean 34.9°, summer mean 71.6°. Because of the arid conditions the nights on the reservation are prevailingly cool and the relatively low mean annual temperatures recorded give little indication of the almost continuous high temperatures of the day. Temperatures exceeding 100° may be experienced for 15 or 20 days each year at Holbrook, Winslow, Tuba, Chinle, Fruitland, Aneth, and Hite. During the summer months the day temperatures in the lower San Juan Valley, the Painted Desert, the Chinle Valley, the Hopi Buttes, and the Tusayan Washes rarely fall below 90°.

The mean relative humidity at Flagstaff, the only station in this region for which records are available, is, for the years 1905 to 1911, 66, 62, 63.5, 59, 73, 57.5, and 51 per cent, respectively, an annual mean of 61.8 per cent. The figures for June drop below 40 per cent. It is colder and much wetter at Flagstaff than in the region to the east, and the relative humidity is consequently higher. For the Navajo Reservation as a whole the estimate of relative humidity may safely be placed below 50 per cent.

High temperature and low humidity are the chief causes for the high figures assigned to evaporation in the Navajo country. At Holbrook the measured amount of evaporation was for 1906, 49.84 inches; 1907, 42.07 inches; 1908, 48.62 inches; 1909, 45.38 inches; a mean of 46.41 inches—that is, the evaporation was 300 to 400 per cent greater than the rainfall (9.15 inches) at this station. In the lower Little Colorado Valley, where the daily range of temperature exceeds 50° and where temperatures of over 100° are not uncommon, rough measurements indicate an annual evaporation of over 60 inches. Since evaporation is directly proportional to the temperature the amount of water capable of being dissipated into the air is greater during the summer, the time when the maximum amount of water is needed for the support of vegetation and to maintain the flow of dwindling streams. The seasonal distribution of evaporation for Holbrook for the four-year period 1906 to 1909 is: Winter, 6.34; spring, 11.20; summer, 18.67; fall, 10.20. Streams therefore are likely to flow with greater regularity during the fall and winter than during the other two seasons of the year. The influence of evaporation is strikingly shown by the well-known phenomenon of increased surface flow during nighttime. In early morning rills are found to have lengthened and to have increased in volume and intermittent stretches to have become through flowing. The amount of stream lengthening, as noted by members of my party, varies between 20 and 1,000 feet. The wiser heads among the Navajos take advantage of this fact and water their herds before the sun's heat has affected the flow.

SOIL.

Bare rock constitutes a large proportion of the surface of the Navajo Reservation outside the larger washes. On the Rainbow Plateau and among the Gothic Mesas 20 to 40 per cent of the surface is bare or strewn only with loose gravel; in the other provinces the amount of exposed rock surface may equal 3 to 10 per cent. The flat tops of the Chuska Mountains and of Dutton and Moenkopi plateaus, Black Mesa, and Segi Mesas are covered with thin soil of high porosity, resulting from local disintegration of sandstone. For the region as a whole the soil is, however, mainly accumulated in the

washes and along the smaller stream channels, where deposits exceeding 50 feet in depth are not unusual. The relatively small amounts of limestone and shale contributed by decomposing ledges gives to these alluvial deposits a composition almost wholly of sand and gravels. Evaporation dries the sands between showers and the streams accordingly find along their courses porous material which imbibes flowing water with avidity.

VEGETATION.

Approximately 5 per cent of the Navajo country may properly be called "forested" in the sense of extensive areas of trees, chiefly yellow pine, exceeding 40 or 50 feet in height. An additional area, perhaps 20 per cent, is covered with piñon and juniper 10 to 20 feet high and numbering 100 to 200 individuals per acre; probably one-half of the remaining 75 per cent of the total area of the reservation is marked by scattered piñon and juniper, with 5 to 20 trees per acre. Sage, greasewood, and grass, widely variable in amount and luxuriance of growth, are found among the trees and between the bare stretches of rock and soil outside the forested areas.

The general effect of vegetation is to lower evaporation by shutting out winds and sunshine, to facilitate the accumulation of snowdrifts, and to retard run-off. The influence thus exerted partly compensates for the loss of water occasioned by transpiration. The nature of the cover of vegetation is, however, a matter of prime importance and the character of the flora on the Navajo country is such that the effect of vegetation on stream flow is not that noted in more humid regions. Leaf mold and forest litter is practically absent except on the Chuska Mountains, Dutton Plateau, and at the heads of valleys on Carrizo and Navajo mountains. At these and other localities similarly situated the horizontal attitude of strata rather than the presence of trees is responsible for the retention of vegetable débris. In the forest on Defiance Plateau (the most extensive area of merchantable timber on the reservation) the trees are wide spaced, and bare rock floor or rock coated with a thin soil deficient in organic material is more extensive than areas covered by pine needles (Pl. XXIII, *A*). On several occasions it was noted that the first shower of summer stripped the ledge bare and filled the watercourses with quantities of cones and other débris. Along the steep slopes trees commonly emerge from cracks in bare ledges. The run-off is somewhat retarded by these open forests and to an even greater extent by the tangle of oak and piñon in the small valleys at the bases of cliffs. Taken as a whole, sagebrush and grass tufts appear to be much more effective than trees in retarding run-off and facilitating soil absorption in this region. At no place observed was the perma-

nence of stream flow affected by forests to any large extent, and it is probable that if the forests of the reservation were replaced by fields of sage and grass and shrubs the behavior of the streams would not be appreciably affected. The storage of ground water likewise appears to be relatively little influenced by the presence of forest cover, and it is believed that for the Navajo country the amount of water which is absorbed by rock and soil, and which later appears as springs at lower levels, depends more on flatness of slope and local depressions than on the distribution of vegetation. This belief is strengthened by a study of the Hopi Buttes, where water falling upon the fissured, roughened surface of lava-capped mesas is led with unusual directness to the springs issuing at the base of the cliffs. On Chuska Mountain, also, the porous Tertiary sandstone dotted with pits and hollows produces the line of springs which emerge at the mountain base.

EROSION OF THE VALLEY FILL.

During the last 20 or 30 years, in consequence of overgrazing and probably, too, of climatic change, the alluvial floors of canyons and washes have been trenched by streams, and the normal valley profile has been changed from a flat-floored, rock-walled gorge to a valley, including an inner canyon 10 to 50 feet deep, whose walls are of alluvium (Pl. XXIV, *A*). This new development has resulted in enlarging the amount and increasing the permanence of stream flow. A number of perennial springs and seeps issuing from the base of the alluvium in the new-made canyons and arroyos have been added to the reservation within the last 30 years, and the amount of surface water has been increased accordingly at the expense of the ground-water supply. My Navajo interpreters state that the flow of Tyende Creek and of the lower Chinle is more regular than formerly, and Mr. A. B. Randall, who has been familiar with the conditions at Tuba since its colonization by the Mormons in 1876–1878, informed me that since 1880, when the Moenkopi began to intrench itself in the alluvium, the permanent flow of that stream has increased 600 to 800 per cent.

WORK OF THE WIND.

Wind-blown sand has affected stream flow on the Kaibito, Shato, Rainbow, and Moenkopi plateaus, in the Little Colorado Valley, and in a lesser degree at other localities. Shallow basins in bare rock, depressions formerly connected with drainage systems, were observed in many places. Dune areas, both shifting and stationary, in the Chinle Valley, the Tusayan Washes, as well as over the western portion of the reservation, have completely masked the normal drainage and in many places hold short-lived pools of water in the hollows between the wind-formed mounds. In the southwestward-trending

A. ROCK COVERED BY THIN SOIL IN FOREST OF DEFIANCE PLATEAU.

Showing absence of forest litter and humus.

B. NAVAJO CORNFIELD.

Photograph by A. C. Vroman.

A. LAGUNA CANYON, SHOWING RECENT TRENCHING.

B. RESERVOIR CANYON, TUBA, ARIZ., IN PROCESS OF FILLING BY WIND-BLOWN SAND.

valleys of the Shato Plateau and in the Klethla and Red Lake valleys the streams are broken into a series of pools and swamps separated by mounds of shifting sands. Parts of valleys leading south to the Moenkopi are completely effaced by sands which have filled the trough to the level of the surrounding country. The process whereby this change is effected may be observed at Reservoir Canyon, near Tuba, which is losing its identity year by year (Pl. XXIV, *B*). The net result of wind erosion and deposition appears to be an increase in quantity of ground water at the expense of surface supplies.

FLUCTUATION IN STREAM VOLUME.

The amount and quality of rainfall and evaporation, the nature of the soil and of vegetation, the effect of recent erosion, and the work of the wind combine to produce great and sudden fluctuation in volume of water carried by the streams of the Navajo country. In general the canyons and washes are alternately flooded and nearly dry during the rainy season and are without water during the spring and fall. On July 17, 1909, the San Juan was 3 inches deep at Four Corners, and July 23 the water at Mexican Hat was 3 feet deep. Following rains of the night of July 24 the river rose 8 feet. During the flood of 1911 the water at Shiprock stood 18 to 20 feet above low-water mark, and in the lower San Juan attained a height of 30 feet above low water. During this year the agency grounds at Shiprock were flooded, and the bridge at that place and also the one at Goodridge, Utah, were destroyed.

In narrow, deep canyons the rise of water supplied by some insignificant tributary is sufficient to render the canyon impassable, a change which may come without warning and necessitate skillful and rapid movements to transfer one's outfit to some shelf of rock beyond the reach of the temporary flood. In May, 1909, water to the amount of about 300 gallons a minute was flowing over Grand Falls on the Little Colorado. In June the stream was dry; by July 20 it had risen 6 feet and attained in places the width of one-half mile. During the course of field work, July 10–21, 1913, no flowing water was found in the Little Colorado between Sunset Crossing and Black Knob. At noon on July 21 the water began to rise and by night had reached a stage where crossing was dangerous. The appearance of this stream at high water is seen in Plate XXV, *A* (p. 110).

During August, 1911, the Pueblo Colorado was observed to rise 13 feet in 4 hours, and in August, 1909, the lower Oraibi Wash, which had been dry for six months, rose during one night to a height which necessitated swimming with the horses. After rains, the Tusayan, Pueblo Colorado, Wide Ruin and Chinle washes, and the streams in Black Creek and Chuska valleys expand in places to form sheets of water ranging in extent from 100 to more than 1,000 acres. Frequently

the rise of water is unconnected with rainfall in the vicinity. The fluctuations in volume of stream are greatest and most sudden in the smaller channels; that the larger streams possess the same character is shown by quantitative measures on the through-flowing streams bordering the reservation. The San Juan in January, 1905, discharged a minimum of 40 second-feet; in June of the same year a maximum flow of 24,800 second-feet was recorded. In July, 1904, this stream reached a minimum discharge of 20 second-feet, as contrasted with 20,000 second-feet in October. The Little Colorado at Holbrook, where this stream is perennial, had a mean discharge of 4.1 second-feet in June, 1906, preceded by 621 second-feet in March. During this year the maximum discharge was 3,540 second-feet, and the minimum 3 second-feet. For November, 1905, the difference between maximum and minimum flow was 20,150 second-feet. Not only is there a great difference between maximum and minimum discharge for each month, but the flow during corresponding months of different years varies from 500 to 1,500 per cent for the San Juan. For the Little Colorado the maxima for November, 1905, and November, 1906, were, respectively, 20,180 and 63 second-feet, a difference of nearly 2,000 per cent.

Engineers of the Indian Office and Reclamation Service need no description of the behavior of fluctuating streams in this region. Gages have been repeatedly washed out or rendered useless by shifting channels. "A gaging station was established on the Pueblo Colorado in November, 1910, but the sandy nature of the river caused a complete change in the channel after every high-water period. Since then the gage has been replaced three times, but the records are incomplete, for the reason that after every change either the gage was washed out or the channel changed so materially that the readings are valueless as to exact quantity."[1] Those who are acquainted with this region retain vivid impressions of the rapid and unpredictable fluctuations of stream volume—impressions based on experiences which involve both hardships and danger. One soon learns to respect the most innocent-looking dry channel and faithfully to follow the rule "Always camp on the other side of a wash" whenever crossing is possible.

UTILIZATION OF STREAMS.

NATURE OF THE PROBLEMS TO BE STUDIED.

The scanty rainfall (see pp. 53–59) considered in connection with its uneven distribution and with the high evaporation and soil absorption indicate the limits within which studies relating to the utilization of streams are to be confined.

[1] Robinson, H. F., superintendent of irrigation, letter to the Commissioner of Indian Affairs, Jan. 29, 1912.

A second consideration is the purpose for which surface water is to be used. If the region is designed for stock raising on open ranges there is little to be gained by increasing the supply of water in the present living streams. For this purpose many small supplies distributed in such manner as to utilize the natural forage is the essential requirement. If the region is to be reclaimed for agriculture, water from streams should be impounded for distribution during the spring and early summer—the growing season—in months which are practically rainless. Because of its elevation (about 43 per cent of the reservation is above 6,000 feet), the alkaline character of the soil over considerable areas, and the lack of plant food in other large tracts probably 60 to 70 per cent of the reservation is at present unsuited to agriculture, and if varied agriculture by irrigation is to be undertaken on a large scale much study needs to be given to the treatment of soil as well as to the utilization of water. Attention must also be directed to the selection of plants adjusted to extremes of temperature, for within the valleys of the most vigorous perennial streams, particularly those of the Defiance Plateau, Chuska Mountains, and Carrizo and Navajo mountains, frost is liable to occur any month in the year. Even if agriculture is to be confined to the cultivation of forage plants similar problems are to be solved.

Again, the future of the district as regards character of the population is an item which must be taken into account. According to the census of 1912 the Navajo and Hopi reservations are occupied by 2,272 Hopis, who are primarily agriculturists but who also practice sheep husbandry; by 30,016 Navajos, who are unusually skillful stockmen; by 200 Piutes, who raise sheep and cultivate small patches of corn; by a few white cattlemen, who use the range outside the reservation lines; and by about 500 officials, missionaries, and traders, present because of the Indians. If the region is to remain as Indian land, the problem is to procure water for stock and, in a minor degree only, for agriculture. The Navajo needs irrigated land in places where he may live the year round, not in mountain districts where corn will not mature and where sheep are driven only when forage is scarce in the lowlands.

FLOOD IRRIGATION.

The streams of all classes are at present partly utilized both for flood irrigation and for irrigation by storage, and improvement and extension of both these methods of increasing the available supply of surface water may be accomplished without prohibitive expense.

The use of flood waters for irrigation has been a feature of agricultural practice in this section of the Plateau province for perhaps a

thousand years. Fragments of check dams of loosely piled stone arranged on sloping rock benches and on the terraced floor of washes may be seen near many of the ruins of the ancient cliff and plateau dwellers. It is probable also that temporary earth dams were constructed by these farmers of early days. The Hopis, the remnants of this nearly extinct race, follow the methods of their ancestors with slavish regard for tradition. The Navajos in turn use the accumulated experience of cliff dweller and Hopi, following irrigation methods centuries old. From experience and tradition the Indians have learned to know the areas liable to be flooded during occasional showers as well as those annually inundated by the successive rains of July and August. Along the flood plains of the larger washes the practice is to plant corn at intermediate levels in widely spaced holes 12 to 16 inches deep. The grain germinates in the sand and rises a foot or more above the surface before the July rains begin. With the coming of the flood the field is wholly or partially submerged. After the water has receded parts of the field are found to have been stripped bare of vegetation and other parts to have been deeply buried by silt; the portion of seeded ground remaining constitutes the irrigated field from which a crop is harvested. (See Pl. XXIII, *B*, p. 100.)

The Hopis, and to a less extent the Navajos, sometimes endeavor to direct the floods and to prevent excessive erosion within the fields by constructing earthen diversion dams a few inches to a foot or more in height—dams which require renewal each season. Along the smaller washes and in places where the slope of the ground is moderate the common practice of the Navajo is to build a series of check dams 50 to 200 feet apart and 2 to 5 feet high, which not only retard the run-off but also serve to form temporary ponds for stock watering. Rarely the valley sides are terraced so that flood waters pass from field to field without developing arroyos. Much work is done by the Indians while the flood is in progress, and an everyday sight during showers is the irrigator at work with hoe or stick, or even with his hands, constructing ridges of earth or laying down sagebrush in such a manner as to insure a thorough soaking of his planted field. By these methods of flood irrigation the Navajo and Hopi together cultivate about 20,000 acres of land widely distributed over the reservation in fields about 3 acres in average size, rarely exceeding 200 acres. Considering the size of fields, the nature of the soil, the fluctuating flow of streams, and the large amount of débris carried in the flooded channels, this method of control by inexpensive dams, rebuilt each season, is satisfactory, but the amount of water lost is enormous. It is estimated that the unutilized flood waters in the Tusayan Washes is 99.5 per cent, a figure which probably also represents the conditions in Wide Ruin, Pueblo Colorado, and Chinle

washes. For the Chuska Valley the estimate is 92 per cent. A part of this water now running to waste could be reclaimed by systematic construction of checks over larger areas and by completely surrounding fields with low earth walls which are designed to retain surplus water for a few days. The use of a road grader would greatly reduce the large amount of manual labor at present expended by the Indians.

IRRIGATION BY DIVERSION.

AREA IRRIGATED.

Along some of the perennial streams of the Navajo country lie alluvial deposits formed of soil suitable for agriculture. In several such places the waters have been diverted by dams and led out onto the adjoining flats. In Piute Canyon, at the Lower Crossing, the waters of a spring-fed tributary are led through a ditch one-half mile long to irrigate 2 acres of garden and orchard owned by a Piute stockman. Standing Redrock Creek, in Redrock Valley, is diverted to water more than 100 acres of cornfield. Lukachukai Creek supplies, through a series of short ditches, water to cover 300 to 400 acres and makes this place one of the most prosperous Navajo settlements in Arizona. Ditches were also noted along the Tisnasbas, Nazlini, and Wide Ruin washes, and at several other localities on the reservation. The Indian dams are all temporary affairs, constructed of earth or of earth, rock, and brush, and rebuilt many times each year. The ditches, too, usually require cleaning after heavy showers. The problem confronting the Indian in reclaiming land by diversion of streams is twofold: The difficulty of securing a permanent intake and the necessity of building sluiceways across innumerable arroyos. This latter difficulty has so far proved insurmountable; many fields have been abandoned as the cutting of gulches has advanced, and it is probable that the mileage of Indian-owned ditch is less at the present time than it was 20 years ago.

PROJECTS DEVELOPED BY WHITE MEN.

Where the Indian has failed the white man has been able to succeed in maintaining irrigation works based on stream diversion. By the use of grading machinery, blasting powder, masonry, wooden and metal flumes, properly constructed head gates, and by systematic attention to repairs, irrigation farming has reached a high stage of development at Shiprock, Fruitland, and Bluff, along the north bank of the San Juan, and at St. Joseph on the Little Colorado. On Wheatfields Creek works designed to supply water for about 700 acres were constructed and later allowed to become useless for lack

of repair. Many failures are, however, to be recorded. Money expended on the Little Colorado below Winslow has been wasted, and attempts to divert the lower Chinle have so far resulted disastrously. Even on the Moenkopi, where rock floor may be obtained for the base of the dam and where satisfactory sites for ditch headings may be obtained, ten or twelve trials have not produced a satisfactory scheme. The most successful irrigation project on the reservation, based on direct utilization of stream flow, is at Fort Defiance, where practically the entire low-water discharge of Bonito Creek is made available. It is significant that at this point the diversion dam is of the simplest type—a low ridge of earth capped by bags of sand—a structure destroyed at each stage of high water, but capable of renewal in a few hours. It appears to me probable that dams of this type, accompanied by headings in rock or masonry and permanent ditches, will be found most suitable for irrigation projects not involving storage.

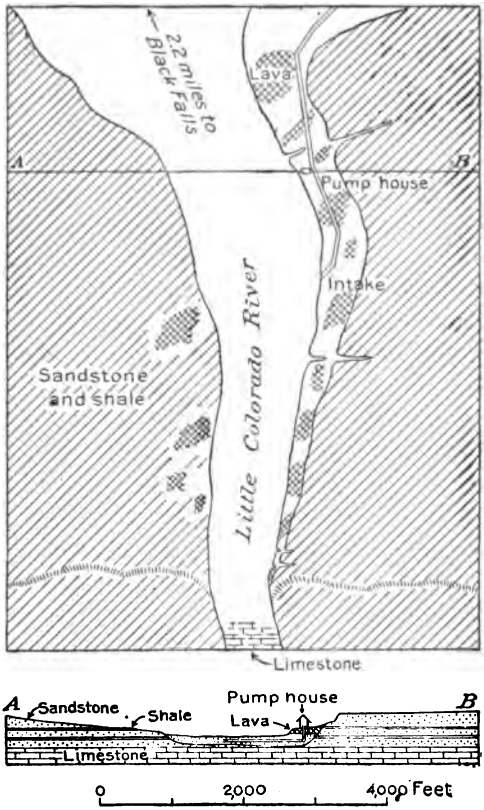

FIGURE 4.—Map and section illustrating features of the Black Falls project.

PROJECTS AWAITING DEVELOPMENT.

In the course of my travels through the reservation I noted a number of places where topography, soil, climate, amount of water, and conditions controlling dam and ditch construction were such as to repay further study with a view to irrigation. In the Tyende Valley below Marsh Pass opportunities for the diversion of the stream are afforded at points where bedrock floors the channel and where, by deep ditches, water could be led to lands favorably situated for irrigation. At Sehili, where some work has already been done, a ditch heading in the mouth of Spruce Brook should reclaim 400 to 450 acres. At Tseanazti, on a stream of the same name flowing eastward from Tunitcha Mountain, there are ancient ditches abandoned because of the headward recession of several arroyos.

Lieut. W. C. Brown, who has investigated the possibilities of irrigation at this point, shows that a ditch 4 miles long would serve to reclaim 1,000 acres of fertile lands.[1] Lieut. Brown has also drawn plans for an irrigation project on Standing Redrock Creek in Redrock Valley at a point where a 20-foot waterfall furnishes a favorable site for an intake. The plans include the construction of a cement dam 2 feet high and 25 feet long and the improvement of the present Indian ditch to cover 2,500 acres of corn land. It is the belief of Lieut. Odon Gurovits that 260 acres could be reclaimed at Tohonadla by the construction of 3 miles of inexpensive ditch. Upper Black Creek in Todilto Park, Nazlini Creek, Tahchito Creek, Shato Canyon, and Figueredo Creek are worthy of further study.

Black Falls, on the Little Colorado, is the center of a wide expanse of desert in which the rainfall probably does not exceed 3 inches a year. The climate and soil, however, favor the practice of agriculture, and at the request of the Commissioner of Indian Affairs an examination was made of this locality.[2] The plan proposed is to divert a part of the flow of the Little Colorado during the months when water is sufficient to form a stream, and to supplement the supply by pumping during May and June. The place selected for ditch head is 2½ miles above the falls at a point where lava forms the immediate bank. No dam is required, and at low-water stages the stream is relatively free from silt. The plan recommended involves the construction of 11 miles of ditch and of an infiltration gallery to recover the underflow of the valley. The water to be recovered will be capable of irrigating 1,200 acres of a 2,000-acre tract which lies east and north of Black Falls at an estimated cost of $25 an acre. (See map, fig. 4.)

IRRIGATION BY STORAGE.

GENERAL CONDITIONS.

At first sight it appears that the Navajo country, with its innumerable narrow rock canyons, its score or more of short perennial streams at high altitudes, and its rapid run-off, offers opportunity for the construction of many storage reservoirs, by means of which the widely extended alluvial plains may be intensively cultivated. When, however, the region is examined the following general conditions are found to prevail:

1. The storage grounds along the perennial streams of the Chuska Mountains and of the Carrizo and Navajo mountains are at altitudes which prohibit the cultivation of crops other than those which survive large ranges in daily temperature and can endure frost at any

[1] 52d Cong., 2d sess., Senate Ex. Doc. 68, 1893.

[2] The reports on the engineering problems of the Black Falls project by H. F. Robinson and a report on the geologic features are on file in the Office of Indian Affairs.

month in the year. Water from reservoirs thus located must be carried 10 to 30 miles before it can reach large tracts suitable for general agriculture. In general the largest tracts of irrigable land are farthest from permanent streams.

2. The deeper canyons—Navajo, Piute, Laguna, upper Moenkopi, Del Muerto, and others now occupied by streams—contain little arable land.

3. The construction of dams for storage of flood water in the wide alluvium-filled washes presents engineering difficulties surmountable only at prohibitive cost—a statement amply supported by a formidable catalogue of failures.

4. The amount of silt carried along the large valleys is sufficient to cause embarrassment, since no satisfactory method has yet been devised for clearing silt-laden streams. Studies of silt at the Zuni Reservoir, 30 miles south of Gallup, N. Mex., where conditions are similar to those in the Navajo country, have been made by Rollin Ritter.[1] At this point, during the years 1912 and 1913, a run-off of 14,450 acre-feet gave a silt deposit of 1,070 acre-feet, having a solid content of 7.4 per cent. During the eight years since the channel was closed the reservoir capacity has been diminished 4,249 acre-feet, an average of 531 acre-feet per year. At this rate the life of this expensive reservoir is 12 years. The proportion of silt, by volume, found in water at the spillway outlet was 16 per cent after the muddy water had been allowed to settle for four months. When first collected a bottle test showed 55 per cent of silt. Because of the nature of the rainfall the water impounded at Zuni and at other localities in northwestern New Mexico and northern Arizona is necessarily that from sudden, violent floods, which carry the maximum amounts of silt. Mr. Robinson found that water collected from the Pueblo Colorado at Ganado and allowed to stand for 30 days carried 2.5 per cent of silt by volume when the stream delivered 15 second-feet of water, and 6.5 per cent when the run-off had increased to 1,940 second-feet. Samples collected by Mr. Robinson in August, 1904, from flood waters of Bonito Creek at Fort Defiance contained 13.5 per cent of mud by volume after a lapse of one month.

At various times during the course of our work tests were made of flood water taken from the larger washes and allowed to settle from 12 to 36 hours. Eight such tests gave an apparent percentage of sediment ranging from 6 to 25. One record of 34 per cent was obtained, and a sample taken from a tributary of the Little Colorado was found after 16 hours to have deposited nearly half its bulk.

5. The alluvial filling of washes and canyons is, in general, fine and coarse sand, rather than silt and clay; the soil absorption and under-

[1] A copy of the report of Mr. Ritter has been kindly furnished me by Mr. H. F. Robinson, superintendent of irrigation.

ground flow is correspondingly large. As stated by Lieut. Baker in a report to the Secretary of War:[1] "Officers should be cautioned in reporting upon the feasibility of any site for a dam, reservoir, or irrigation system that the sandy and porous nature of the soil should be taken into consideration, as well as the limited amount of rainfall and high evaporation, and consequently the difficulty not only of filling a reservoir but also of preserving the water until the irrigation season begins."

A preliminary study of the reservation, supplemented by the experience of settlers in the arid Southwest, indicates that wisely located irrigation works costing between $10,000 and $40,000 may justify their construction, provided the problems which they present have been carefully studied. More expensive projects are of doubtful expediency.

GOVERNMENT PROJECTS.

Red Lake.—The storage reservoir of Red Lake (Pl. XXV, *B*), 12 miles north of Fort Defiance, was designed to irrigate several hundred acres of land in the middle of Black Creek Valley. The "lake," 59.82 acres in extent, receives short, ephemeral tributary streams but is mainly supplied by upper Black Creek, whose waters are diverted by a flume and dam. The drainage area, calculated by H. F. Robinson, is 230 square miles, and the run-off is 2.5 inches, or 33,325 acre-feet per year. The reservoir is well placed and well designed, but the ditches have been neglected until they are washed out or filled with sand. The only use to which this body of stored water has been put in recent years is for flood irrigation along Black Creek Valley, and at critical times to supply Indian farms located at Houck, 48 miles below the reservoir.

Reservoir Canyon.—Two miles east of Tuba is a spring-fed canyon containing three lakes. The upper and middle lakes (respectively 10 and 6 acres in area) are caused largely by wind-blown sand, which is gradually filling the canyon. The waters of the lower "lake" or reservoir, with an area of about 15 acres, are retained by a dam 350 feet long and 5 feet high. About 75 acre-feet is drawn off during the growing season. Plans formulated by the irrigation engineers of the Indian Office involve impounding about 150 acre-feet, and the construction of ditches to irrigate lands in Moenkopi Wash, as well as within the canyon itself. (See map, Pl. XXVII.)

Wheatfields reservoir.—A ditch leading water from Wheatfields Creek was constructed by the Indian Office in 1885–86 and utilized to irrigate a few acres of land. Later it was decided to construct a diversion dam, reservoir, and the necessary ditches to irrigate 700 acres on the south side of the creek. The reservoir, completed in

[1] 53d Cong., 2d sess., S. Ex. Doc. 68, 1893.

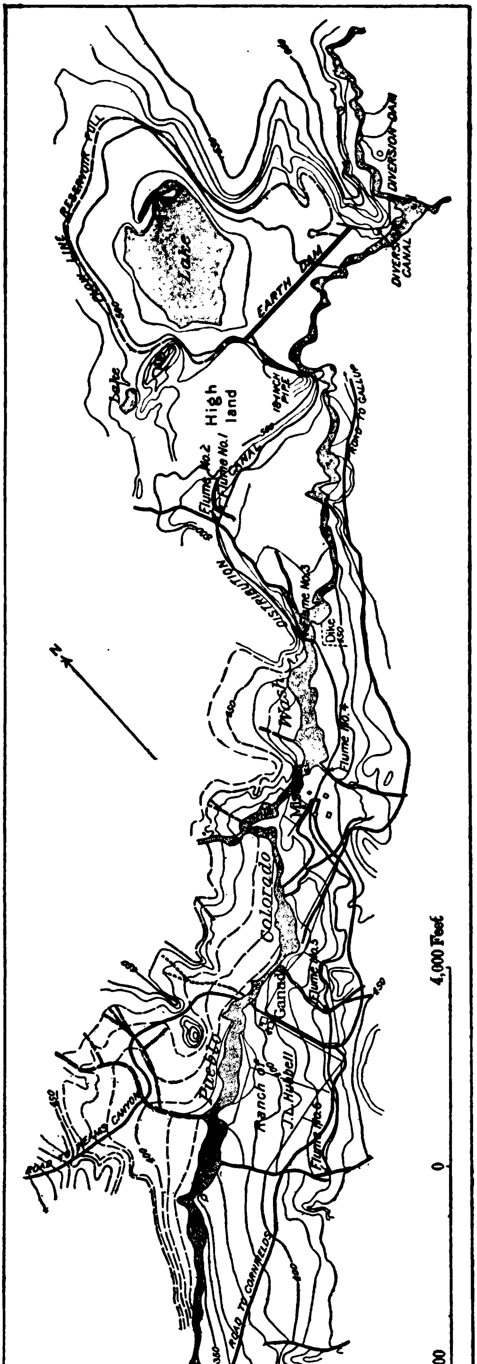

FIGURE 5.—Map of Ganado irrigation project. From maps furnished by Office of Indian Affairs.

1909, has a capacity of 1,300 acre-feet. At the time of my visits, in 1909 and 1911, the works were out of repair and had apparently been abandoned. In a report to the War Department in 1893 Lieut. W. C. Brown called attention to the fact that 10,000,000 gallons of water could be impounded on upper Wheatfields Creek by an earth dam 300 feet long and 20 feet high.

Ganado reservoir.—Ganado is a short distance below the mouth of the canyon portion of Pueblo Colorado Wash. The stream at this point is perennial, and extensive flats below consist of fertile soil well situated for irrigation. Three miles above Ganado is a natural lake which rarely becomes entirely dry. From time to time the waters of this lake, supplemented by flow from the Pueblo Colorado, have been utilized by means of low earth dams and distributing ditches constructed by the local trader, Mr. J. L. Hubbell. Since the water to be stored at this place is for the benefit of the Navajos my recommendation (report for 1909) was added to that of other Government officers that a suitable dam,

A. LITTLE COLORADO RIVER AT TANNER CROSSING AFTER HEAVY SHOWERS.

Photograph by Stephen Janus.

B. RED LAKE RESERVOIR, LOOKING SOUTH TOWARD OUTLET.

A. OUTLET OF BUELL PARK, LOOKING DOWNSTREAM.

B. SPRINGS AT ST. MICHAELS.

Zone of emergence marked by vegetation.

headgate, and ditches be constructed according to plans outlined by Mr. H. F. Robinson, irrigation engineer, and it was gratifying to see this work near completion at my visit in 1913. (See fig. 5.)

The drainage area above the reservoir, comprising about 205 square miles, is in large part forested and grass covered. The storage basin is designed to hold 4,438 acre-feet of water, which, on the assumption of a duty of water of 2.5 feet, is sufficient to irrigate 1,775 acres of tilled land with each filling of the reservoir. By storing the water at low stages of the creek the difficulties arising from deposits of silt are largely eliminated. The system is capable of expansion, and Mr. Robinson has devised plans for disposing of a large part of the silt if it should be found desirable to utilize flood waters. The estimated cost of the Ganado project is $35 an acre.

PROJECT AWAITING DEVELOPMENT.

Leupp reservoir.—The impracticability of utilizing the flood waters of the Little Colorado for irrigation at Leupp has led to a study of a scheme whereby the flood water of Canyon Diablo and tributary streams, draining an area of about

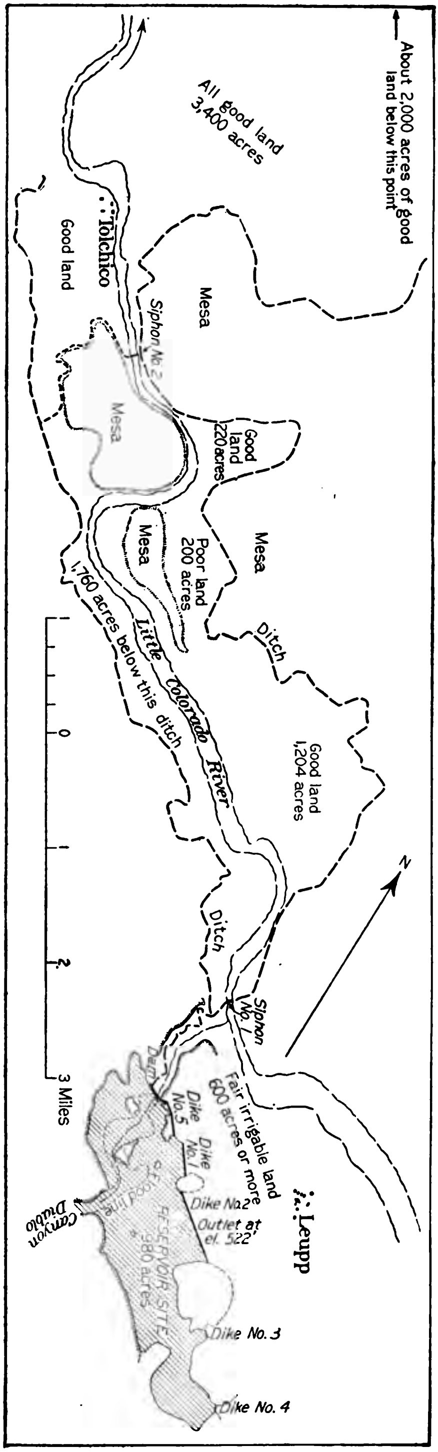

FIGURE 6.—Map of proposed irrigation works at Leupp, Ariz.

1,220 square miles, may be impounded. Completed plans for this project have been submitted to the Indian Bureau by the district supperintendent of irrigation, Mr. H. F. Robinson. The reservoir as designed covers 980 acres, has a capacity of 11,617 acre-feet, and the run-off is estimated as sufficient to fill it 14 to 19 times per year. The area for which irrigation is desired is 8,000 acres, requiring 28,000 acre-feet of water, or 2.4 times the capacity of the proposed reservoir. Fourteen miles of ditch on the north side of the Little Colorado and 10 miles on the south side, including a siphon under the river bed, are a part of the plan. Preliminary estimates place the cost of the Leupp project at $282,786, or $35.35 per acre. (See fig. 6.)

ADDITIONAL PROJECTS.

The following localities, briefly examined by me, are suggested as worthy of detailed study:

Quartzite Canyon.—A perennial stream, flowing about 0.15 second-foot during dry seasons, emerges abruptly from high walls of quartzite and enters an alluvial flat. Back of the canyon gates the valley widens. A dam 30 to 60 feet long and 10 to 20 feet high, at one of several sites, would serve to increase largely the acreage now cultivated at Fort Defiance.

Buell Park.—Buell Park is a rock-walled depression, 10 square miles in area, which receives the waters from 40 square miles of surrounding country. The park has but one outlet, a canyon about 70 feet wide at the base, cut in solid rock with flaring walls 200 feet high. A permanent stream discharging 0.05 a second-foot at low water occupies the canyon floor. Land suitable for irrigation borders the valley below. (See Pl. XXVI, *A*.)

Lokasakad.—A group of springs issuing from the lava 5 miles west of Indian Wells feeds a perennial stream which enters a wide, flat-floored, rock-walled valley, from which it emerges through a cleft 300 feet wide. The spring flows at the rate of 10 to 15 gallons a minute. Other small springs discharge into the valley, which during rains is filled to overflowing. The valley floor is relatively free from silt. More irrigable land than can be supplied with water is conveniently situated.

Marsh Pass region.—The mouth of Laguna Canyon, as well as points lower down on Tyende Creek, where this stream passes from rock canyon to open flat in its sinuous course through Comb Ridge, is worthy of examination with a view to the construction of storage reservoirs.

Segihatsosi.—A running stream, discharging about 0.20 second-foot during dry seasons, occupies Segihatsosi Canyon, and numerous springs are found along its course. At its head is a rock-walled

amphitheater entered by a canyon 200 to 300 feet wide, below which the tiny stream is bordered by alluvial terraces, which increase in area downstream. Irrigation is practiced here on a small scale by a group of industrious Navajos.

Miscellaneous.—The drainage areas of several ephemeral and intermittent streams which flow westward from Defiance Plateau into Wide Ruin Wash and into Nazlini Valley are forested and furnish only a moderate supply of silt. Narrow canyon mouths are abruptly followed by irrigable flats. Along both the north and south edges of Dutton Plateau and on Shato Plateau similar conditions prevail. Flood waters from canyon heads on Carrizo and Navajo mountains may be stored for distribution to lands 2,000 feet below. The eastern half of Monument Valley contains a number of satisfactory sites for reservoirs, but the alkaline content of the soil in this area may render agriculture unprofitable. Two small reservoirs at Toadlena admit of further improvement.

STORAGE OF SURFACE WATER FOR STOCK.

ESSENTIAL CONDITIONS.

The Navajo is a herdsman; the Navajo country is primarily a sheep range; and for the present generation—probably for many generations to come—agriculture will play a decidedly subordinate part in the life of the natives. The problems to be solved, therefore, relate to forage and animals on unpeopled stretches rather than to agriculture and markets and cities. Water for stock rather than water for crops is demanded by the Indian; not a few large supplies, but many small ones; not an increased amount of water where water is, but an increase in the number of places where water may be found. Sheep do not travel far to water, and the Navajo and Hopi practice of returning their flocks to their fold each night requires water so located as to take advantage of the natural feed on the reservation. Under the present conditions the Navajo saying is appropriate: "Where feed is there is no water; where water is there is no feed." Moreover, especially on the lowlands, forage is scant, even as measured by semiarid standards. For horses, and in many places for sheep and goats, the search for grazing ground must often be satisfied by the discovery of places where animals may keep from starving. Water holes should therefore be widely distributed, and the ideal method of development is to provide moderate supplies at points not to exceed 8 miles apart over the entire reservation, each supply sufficient to care for 500 to 1,000 head of sheep. To fulfill these conditions the storage of surface waters and the recovery of ground water are essential.

SMALL RESERVOIRS OR "TANKS."

SITES.

The larger washes, particularly those through which great volumes of water rush in times of floods and those whose banks consist of sand or adobe, are to be avoided in the construction of ponds or catches. The great and fluctuating volume of water, the character of the stream bed, and the presence of silt, present problems which have not yet been satisfactorily solved by hydraulic engineers. Inexpensive storm-water reservoirs may, however, be constructed in many places by paying careful attention to the selection of sites, the construction of the dam, and the position of the wasteways.

Sites for a small reservoir should be selected near the heads of washes or on tributaries, especially those which do not have steep gradients. In fact, the flatter the valley the better. A valley covered with grass, sunflowers, sagebrush, or greasewood, backed by slopes forested with piñon and juniper, should be selected if possible. The reservoir should be so located that the prevailing southwest winds will not have an opportunity to drive waves against the embankment, a matter which is often overlooked, but is of considerable importance, even in a small reservoir where the dam is constructed of earth. Care should be taken also not to place the reservoir directly across the valley axis, but slightly to one side so that the rush of storm water does not spend its full force against the embankment. By keeping this fact in mind, it is possible to place reservoirs along the sides of the larger washes where they may be filled by a part of the storm water without danger of destruction. In some places, also, a ditch may be dug to conduct the water from the main wash to the reservoir and the temporary head gates may be renewed after each storm.

A number of places were noted where natural depressions in bare rock could be utilized by constructing small dams across poorly defined outlets.

DAMS.

Suitable material for earth dams is not abundant in this region, and more than ordinary care should therefore be exercised in their construction. After the site has been chosen ground should be cleared by removing the porous top soil, together with weeds, plant roots, etc., and the material thus removed should be taken outside the reservoir basin. A trench or series of trenches 4 to 10 feet wide and about 2 feet deep may then be dug along the axis of the proposed dam and the entire surface over which the dam is to be built roughened. Such procedure improves the chance of securing a tight bond between the earth and the dam, thus decreasing the seepage along the natural water channel.

The dirt from the dam should be put on carefully and spread evenly in layers 12 to 18 inches in thickness, and each layer should be tamped by hand or by driving horses back and forth over it. This method of treatment tends to prevent the formation of horizontal and vertical seams. No dirt for the embankment should be taken below the dam, for the holes thus made may fill with water, which by percolation may weaken the foundation of the dam. Where borrow pits are made inside the reservoir, care should be taken to leave a berm at least 8 feet from the foot of the slope in order to prevent sliding. If built of loose earth the dam should be at least 10 feet wide at the top and the slopes should be less than those of ordinary dirt banks. Hydraulic engineers have found that a slope of 3 to 1 on the side next the reservoir and of 2 to 1 on the outside will give satisfactory results. Personal experience in planning reservoirs for stock on the Great Plains suggests that an earth dam in an exposed situation should be as wide and as flat as the local conditions will allow.

The material used in the construction of the embankment must necessarily be that which can be obtained near at hand. Many places on the Navajo and Hopi reservations, as in the Chinle, Black Creek, and Little Colorado valleys, furnish clay from decomposed shale. In other places nothing but sand is at hand. Where material may be selected it is of course more important to place the impervious material on the inside of the dam. Care should be taken to avoid soils which contain alkali, salts, or other materials which may be readily dissolved by the water. Where the material is not satisfactory it can be much improved by puddling. Horses or cattle or sheep driven through the reservoir and over the dam when in process of construction help much in producing water-tight material. A dam may be further strengthened by facing with rock and in a number of localities abundant thin slabs of sandstone and shale are at hand for this purpose.

The most satisfactory small dam seen on the reservation is on the trail between Ganado and Keams Canyon and was constructed by an Indian, as follows: Two rows of posts 10 feet apart were made into fences by weaving brush from post to post. The space between the fences was filled with sand and clay collected from neighboring slopes and puddled by driving sheep back and forth between the fences. A spillway leading across bare rock into an adjoining gulch accommodates the surplus water. Many such dams built with the aid of wheelbarrows or scrapers are in use by stockmen on the Coconino Plateau and generally throughout the semiarid portions of the United States.

Immediately below the dam constructed to hold the surface water will usually be found a favorable site for a shallow well suitable for domestic supplies.

WASTEWAYS.

Natural wasteways should be selected where possible and care taken not to allow too much fall between the point where the water leaves the reservoir and where it reenters its old channel. This fact should also be kept in mind when an artificial wasteway is to be constructed, for the fall which forms at the lower end of the waste channed may eat backward with great rapidity. Where feasible wasteways may be provided in the direct line of the natural stream flow, though they should be placed not on or near the earth dam but rather as far away as the topography will permit and at least 5 feet below the top of the dam. Brush checks made of mattresses of greasewood, sagebrush, piñon, and cedar fastened by wire may be constructed along the spillway, and in favorable localities drifting sand may be directed to build dunes which may accomplish the same result.

The following publications will be found helpful to those charged with the responsibility of assisting the Indian in developing water for stock:

Herman, T. C., Small reservoirs in Wyoming, Montana, and South Dakota: U. S. Dept. Agr. Office Exper. Sta. Bull. 179, 1907.

Fortier, Samuel, and Bixby, F. L., Earth-fill dams and hydraulic-fill dams: U. S. Dept. Agr. Office Exper. Sta. Bull. 249, pt. 1, 1912.

WATER POWER.

A small mill for grinding grain, driven by water power, may be constructed along any one of the several perennial streams descending from the mountains. I am informed by Mr. Randall that such a mill was formerly in operation at Tuba.

In the canyon of the San Juan, beginning 3½ miles below Goodridge, is a series of closely set meanders intrenched over 1,000 feet below the surface. The necks between the several meanders vary from 500 to 1,000 feet, and the gradient of the stream is such that at one point the opposite ends of a tunnel 840 feet long would rest, respectively, 10 and 85 feet above low-water level. An engineer's report on a project at "Gooseneck" indicated that a tunnel 600 feet long would serve to develop 740 horsepower at low-water stage.[1]

LAKES.

LAKES OF THE CHUSKA MOUNTAINS.

Basins occupied by permanent or by short-lived water bodies are found on the Chuska Mountains and also on the floors of a few of the larger washes. The basins on the Chuska Mountains are more than 100 in number and vary in size from shallow depressions 10 to

[1] Data supplied by Mr. A. L. Raplee, of Bluff, Utah.

20 feet in diameter to bodies of water covering 1 to 3 acres. Many of the lakes rest in rock-rimmed hollows in sandstone or lava; others are bordered by meadows; and a few are set in the midst of groves of oak and pine and willow, constituting attractive camp sites. In none of the lakes examined did the water exceed 10 feet in depth, and in many of them the water forms merely a sheet 1 to 2 feet deep, covering a flat-floored hollow. During the rainy season most of the lakes form part of drainage systems whose low gradients are determined by the horizontal attitude of the strata along their courses; a few lakes retain their individuality throughout the year. All the mountain lakes fluctuate in volume, but probably half the basins retain water during the dry season. In July, 1909, the lakes at Roof Butte were dry; in July, 1911, 14 water bodies were noted on the Lukachukai Mountains. Lieut. Gurovits reports that the seven lakes seen by him on Tunitcha Mountain in October, 1892, were only water holes and that two of them were nearly dry. Judging from reports of Navajos and Government officials, about one-third of the 41 lakes mapped on the Chuska Mountains are liable to disappear during the spring and early summer.

TOLANI LAKES.

On the route from Leupp to Oraibi there is a group of lakes known to the Navajos as Tolani (many water bodies). The group consists of seven basins in addition to several adobe flats. They are set in the midst of a most forbidding expanse of sands deposited by flood waters of the Tusayan Washes and redistributed by the winds. The lakes occupy a divide at the junction of several washes and are separated from the normal drainage by banks of alluvium and wind-blown sands. They are fed by flood waters supplemented by underground seepage, and downward percolation is prevented by a floor of shale and of adobe. Four of the lakes, so the Navajos state, each 6 to 15 acres in extent, are never dry, in spite of excessive evaporation, and three others are filled by early rains. During the rainy season the low-water depth of 3 to 8 feet is more than doubled and the lakes expand, submerge the adobe flats, and reach the outer strand 300 to 1,000 feet back from the line marking the low-water stage. The lakes form the home of a group of Indians whose flocks graze in the neighborhood.

LAKES FORMED BY DRIFTING SAND.

On Kaibito and Shato plateaus, and to a less extent elsewhere, stream channels have been divided into segments by drifting sands. Red Lake Valley, Klethla Valley, Shato and Begashibito valleys, and Reservoir Canyon, are occupied by ephemeral streams which find themselves unable to contend successfully with the sediments

deposited by the wind. Lakes are accordingly strung along these canyons at irregular intervals. These water bodies are narrow, attain lengths of 30 to 200 feet and in general are clear, fresh, and bordered by zones of reeds and water grass. About one-half of the 10 or 15 lakes observed are perennial; the others become marshes or playas during the dry months. The largest of the group is Red Lake, two partly detached bodies of brackish water about one-half mile in total length, whose volume and area varies widely with the seasons.

EPHEMERAL LAKES.

Numerous depressions floored by adobe or sand and cut off from drainage lines by deposits of sediment from tributary washes or by sand dunes are to be found along the borders of the larger valleys. These hollows contain shallow water bodies for periods ranging from a few days to six or seven months in each year. The water is often turbid from stirring of the bottom by waves and in places is brackish or alkaline. Several such "dry lakes" are found in the Chinle Valley, the largest of which, Bekihatso, has been known to hold water throughout the summer months. Beds of ephemeral lakes were also noted along the southern edge of Black Mesa, within the Hopi Buttes, the Tusayan Washes, and the Chuska Valley provinces; and the glistening, burning floors of three ephemeral lakes in the Little Colorado Valley were crossed during the early summer of 1913.

OTHER LAKES.

Three lakes on Dutton Plateau and nine lakes on the Chaco Plateau were found to contain water during the driest part of 1911. The floors of these lakes are formed by shales of the Cretaceous period and their waters are confined by widespread deposits of silt and sand in the form of low-grade fans, which change in position from year to year. Two small ponds of the same nature were seen on Black Mesa and one on the Shato Plateau.

UTILIZATION OF LAKES.

As reservoirs for irrigation the lakes of the Navajo country have little value. They are too low set for use on lands in the immediate vicinity, and their volume of water is too small to justify the expense of transportation by ditches. Moreover, the lakes on the Chuska Mountains are at too great an altitude (9,000 feet) to be used for crops requiring a long growing season. They, however, furnish sites for the construction of storage reservoirs. The basin is ready prepared, and an increase in the amount of water impounded may be obtained by constructing a suitable dam. Two

storage reservoirs constructed by the Government—Red Lake and Ganado—make use of natural lakes. Bekihatso Lake and an ephemeral lake bed about 6 miles northwest of Sunrise Springs, and two of the Seven Lakes group on Chaco Plateau, are worthy of study with irrigation in view. At the present time the lakes of all types are utilized for stock watering, and from several of them greater permanence and increased volume could be obtained by means of inexpensive dams—a method employed by cattlemen on the lands adjoining the reservation.

WATER HOLES IN THE WASHES.

Rock-floored channels are in a number of places marked by potholes and cavities produced by widening of joints and by solution. They are particularly likely to be found immediately above and below dry waterfalls. In some of these pockets water remains throughout the year and constitutes a reliable supply in an otherwise desert stretch. Water from such rock holes was used by my party at Agathla, at Keams copper mines, at the north base of Dutton Plateau, on Defiance Plateau, at Grand Falls, and at a few other places. After floods in the washes pools of water remain for weeks and sometimes throughout the year. Such water holes are distributed along the dry bed of the Little Colorado, where their preservation is due to scour, which forms a depression below the water table. Depressions floored with a film of silt or adobe, which prevents percolation, may likewise hold remnants of a flood for long periods. Abandoned high-level meanders in adobe flood plains observed along the Chinle, the Dinnebito, and Steamboat washes were found to contain water even during the dry season. These supplies are not, however, to be relied upon, for their position and permanence may vary widely during the season.

DIRECT UTILIZATION OF RAINFALL.

GENERAL CONDITIONS.

In parts of the reservation where surface water and springs are absent and where wells are too expensive to justify construction supplies for domestic use and for small flocks may be obtained by storing rain water. Cisterns for travelers and for teams might be constructed on the long roads which must be traversed on entering the reservation and in going from place to place across it; and the amount of water available at stores, missionary settlements, and Government headquarters might be increased by similar means.

Collected rain is particularly desirable where the present water supply, though sufficient in amount and available for stock, is unsuited

for man because of the presence of alkali or salt. For instance, at Red Lake, northeast of Tuba, the surface, spring, and well waters are unfit for drinking, but an ample supply for household use is obtained by impounding the water which falls on half the store roof. At this place the water is conducted into a cement-lined cistern 6 feet in diameter and 11 feet deep. Every building on the reservation should be supplied with rain troughs and cisterns, for there are few places where rain water is not more desirable for domestic use than the supplies now at hand.

Clean rock surfaces may also be used to collect rain water by constructing small cement dams at the foot of slopes; and it is entirely feasible to clear off hillsides, cover them with cement, and make a shallow collecting basin from which water may be directed to a suitably constructed cistern or closed basin below. Rain water, if kept clean, is palatable and entirely wholesome, and its storage offers one of the best opportunities to meet the demand for good drinking water in this region.

WATER CATCHES.

Water catch is a term in use in Bermuda, India, and other English colonies for a natural or artificially constructed surface from

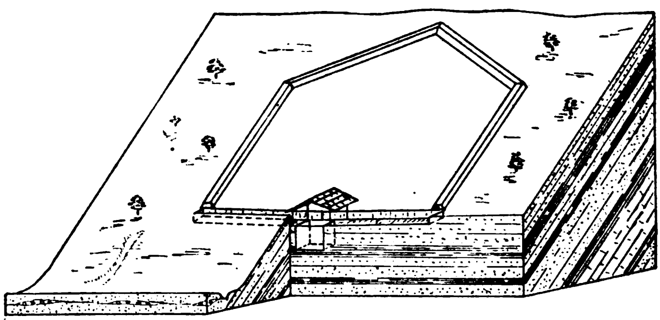

FIGURE 7.—Diagram of water catch with cistern excavated in rock.

which rain water is collected. This system of recovery of rainfall involves the selection of a suitable site and the selection or construction of a catchment or collecting area and the building of a cistern. On the Navajo Reservation sites for water catches are recommended in the following order:

1. Sites at which the natural dip of the strata is from 10° to 30° and erosion has cut the upturned beds into a series of hogbacks. Expense is lessened by the selection of places where the inclined rock surface is free from vegetation or accumulated débris. Such situations are found in the valleys along the western edge of Manuelito Plateau, the west base of Chuska Mountain, in Monument Valley, in

middle Chinle Valley, and along the west side of the Little Colorado, in all of which places water is difficult to obtain.

2. Slopes formed of rock thinly covered with soil or with vegetation.

3. The sloping bare rock walls of canyons cut in a single sandstone stratum. Hundreds of such sites may be found on the Moenkopi, Kaibito, and Rainbow plateaus, on Segi Mesas, in Monument Valley, and in smaller numbers elsewhere.

4. Exposed edges of a series of horizontally bedded rock forming the sloping flank of mesas and buttes and ridges. In such places the edges of strata should be leveled to an even surface—a somewhat expensive operation. By this method supplies of pure water could be developed in the "badlands" of the Hopi Buttes province, in the Painted Desert, and in Gypsum Valley—regions now almost useless because of scarcity and unwholesomeness of both surface and underground waters.

5. Slopes of material other than rock, involving coating the hillside with a layer of cement.

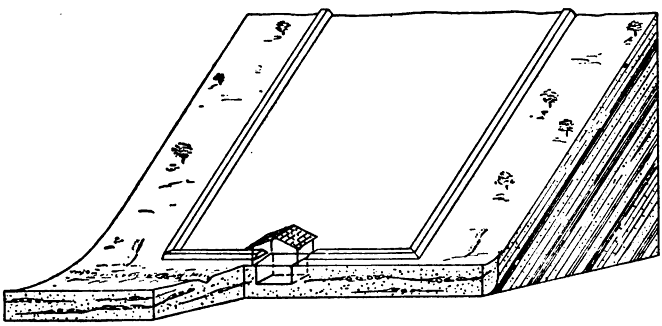

FIGURE 8.—Diagram of water catch with cistern excavated in alluvium at base of a slope.

Construction work on the catchment area is of a very simple character. Bare rock cleaned or rock coated with cement will receive the rain. Smoothing of the rock is desirable but not essential. Bounding walls a few inches in height to turn off water not falling on the cleaned area, and a fence to ward off stock should be provided. The cistern may be constructed either below or above ground and either within or without the catchment area. Cisterns sunk into rock or into alluvium at the base of the inclined collecting area and lined with cement are subject to only slight losses from evaporation; those built above ground are easier to clean and may be so placed as to be drawn off by pipes to troughs located farther down the slope. (See figs. 7 and 8.)

Water catches may be built of any desired size, and in considering the requirements for a given place or a particular purpose the following estimate may be used: One inch of rainfall will yield about

half a gallon of water to the square foot of horizontal catchment area.

On the island of Bermuda, where the entire population is supplied by water catches, the hill slopes are cleared of soil and vegetation and the bare rock is smoothed and frequently whitewashed or cemented. The cisterns are built with thick stone walls, are kept dark and tightly closed from wind-blown sand, and some are whitewashed or painted to retard evaporation. The water is cool and is pure so long as the tanks are kept clean.

If it should be found desirable to store rain water in places where long, sloping surfaces are not available, a modification of the design

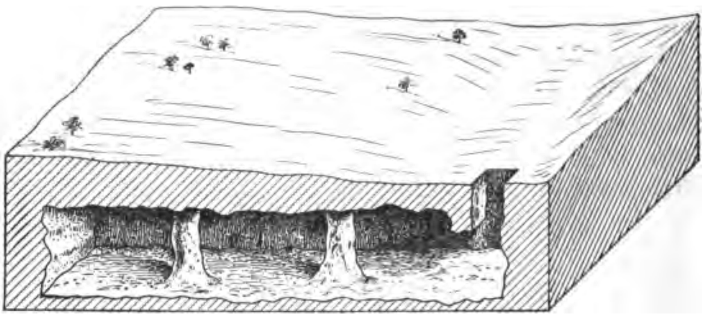

FIGURE 9.—Diagram of water catch constructed in rock on top of a mesa.

for the typical catch is suggested, as shown in figure 9. The essential features of this design are a shaft or well sunk into rock and a gallery or drift leading from it. The gallery may be made as spacious as desired, but the shaft should have the smallest cross section consistent with the demands of construction. The loss from evaporation is thus reduced to a minimum. The catch or cistern should be placed in a depression surrounded by bare rock, but the catchment area need not be large, as the water falling on a cleared space only 100 by 200 feet in area with a rainfall of 8.29 inches, the annual average for this region, would amount to about 83,000 gallons.

Part III. GROUND WATER.

SOURCE OF THE GROUND WATER.

Of the annual precipitation a part finds its way directly into stream channels and constitutes the run-off; a second part is lost through evaporation; the remainder is absorbed by the ground, in which it remains indefinitely as ground water or finds its way to the surface through springs, or seeps, or wells. The proportionate amount of water which is retained by soil and rock varies widely and depends on the relative values of several factors, chief among which are the amount of precipitation, the nature of the precipitation, the rapidity of run-off, the amount of evaporation from both water and ground surface, and the absorbent capacity of soil and rock.

In the Navajo country the average mean annual precipitation is about 8.29 inches. Were other conditions favorable, this amount of rainfall would be sufficient to saturate the ground and to maintain a water table at moderate depth beneath the surface. The rain, however, occurs as sudden showers of short duration, and days or weeks or even months may intervene between falls of rain sufficient to wet the ground. Moreover, the water which falls as rain is in many places hurried away through thousands of ready-prepared channels of steep gradient, with the result that the rocks over perhaps 50 per cent of the reservation are permitted to imbibe an inappreciable amount of the rainfall. It is for this reason that the snow which falls each winter over about half of the reservation has high value, since melting of snow is a relatively slow process and the water resulting is given an opportunity to find its way downward through cracks and pores into the rock. The numerous springs on Chuska Mountain and other flat-topped highland areas are in part traceable to waters originally accumulated as snow.

Evaporation is a factor of prime importance when the final disposition of precipitation is considered. The measurements at Holbrook show that 46.4 inches of the upper surface of a standing body of water may pass into the air each year, and that the rainfall of a day may be dissipated by evaporation within the same length of time. Just what proportion of the rainfall on the Navajo Reservation is lost through evaporation is unknown, for no formulæ have been constructed which make it possible quantitatively to divide precipitation into run-off, ground water, and vapor. For this region run-off prob-

ably averages between 14 and 25 per cent of the total rainfall, and evaporation disposes of most of the remainder.

A portion of the water contained in the soil and rock of the Navajo country finds a source beyond its borders. An unknown amount is fed into the strata buried beneath the northern part of the Gothic Mesas, and the Pennsylvanian and Permian (?) rocks dipping north from the Zuni Mountains doubtless carry water beneath the Dutton Plateau. It is probable also that the sandstones and porous limestones of Carboniferous age underlying the Little Colorado Valley contain water that enters these beds in the well-watered area about San Francisco Mountain. With these exceptions the water found in bedrock and in unconsolidated material probably has its source in the rain and snow falling within the borders of the reservation.

GROUND-WATER RESERVOIR.

NATURE OF THE RESERVOIR.

The surface of the ground is the top of a vast underground storage reservoir, or the outer surface of a sponge whose pores are more or less completely filled with water. The surface of this gigantic sponge or reservoir is by no means level and even, but coincides with

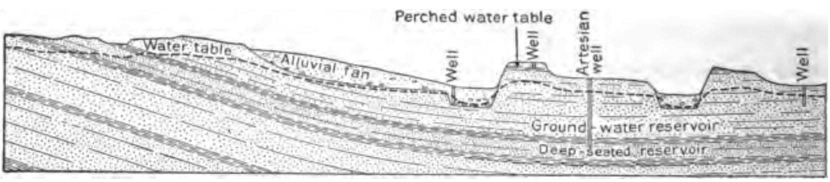

FIGURE 10.—Diagram showing distribution of ground water and the position of the water table.

the surface of the ground, reaching an elevation of more than 10,000 feet on Navajo Mountain and sinking to 2,800 feet at the mouth of the Little Colorado. Even if the reservoir were filled the surface of the water would not attain a uniform level, because free adjustment among water particles is prevented by the presence of impervious areas and by the fact that much of the water is in control of capillarity rather than of gravity. The bottom of this underground reservoir is likewise highly uneven, for the water in the ground can extend downward only so far as openings exist and to the point at which the strata are water-tight.

In some parts of the reservation there is a second reservoir, a deep-seated sponge separated from the upper ground-water reservoir by an impervious bed of shales or other materials, and receiving its water supply from some distant source. (See fig. 10.)

CAPACITY OF THE RESERVOIR.

VARIATION IN POROSITY.

Water is held in the ground-water reservoir in cracks and in open spaces between the constituent grains and in zones between strata. The amount of water that may be held is determined by the number and size of all void spaces within the soil and rock in which the water is stored. The percentage of void space, called "porosity," varies greatly in different materials and is largest in rocks composed of imperfectly cemented, rounded grains, and in rocks shattered and broken and traversed by cracks. The porosity of a rock or soil is expressed as a percentage of the entire volume. Thus, if 100 cubic feet of sandstone can absorb one-fifth of this volume, or 20 cubic feet of water, the rock is said to have a porosity of 20 per cent. On the Navajo Reservation the bedrock consists of sandstones and shales with lesser amounts of lava and of limestone. The water-holding capacity of the various strata whose extent and outcrops are indicated on the geologic map (Pl. II, in pocket) is roughly estimated in the following paragraphs.

BEDROCK.

The Pennsylvanian formations consist of sandstones and limestones with variable amounts of shale. The sandstone will absorb about 12 per cent of its volume; the limestones and shales are practically impervious.

The Moenkopi (Permian?) formation, of shales and thin sandstones, has been found to contain water between the beds wherever these rocks have been penetrated below the water table. The massive sandstone beds overlying the Moenkopi formation have a porosity of about 15 per cent. The quality of water from the shales of the Moenkopi formation is liable to be unsatisfactory.

The Shinarump conglomerate is capable of holding about one-fourth gallon per cubic foot, and the plane of division between the Moenkopi and the Shinarump is one of the best saturated zones within the region and gives rise to many springs.

The Triassic beds overlying the Shinarump conglomerate are composed largely of shales and massive limestones and have a small water capacity. Large parts of them hold no water in available form.

The massive sandstones of the La Plata group have high porosity, and tests made on average specimens indicate that these sandstones may hold 1 quart of water per cubic foot. That these beds contain water in large amounts and that movement within the rock is easily

accomplished is shown by the numerous seeps and springs emerging from the rock face.

The McElmo formation is closely similar to the upper sandstone of the La Plata group as regards porosity.

The Dakota sandstone has large capacity for holding water, both between the constituent grains and within its innumerable open cavities.

The Mancos formation is essentially shale with subordinate amounts of sandstone. The shales are practically impervious and two samples of sandstone tested showed a porosity of about 10 per cent.

The sandstones of the Mesaverde formation have a porosity of 8 to 12 per cent, and constitute one of the chief water carriers of the Navajo country.

The Chuska (Tertiary) sandstone ranks next to the Dakota in its capacity to hold water.

The lavas of the Chuska Mountains and of the Hopi Buttes are practically water-tight but are so intersected by joints as to absorb nearly all the water which falls directly upon them.

UNCONSOLIDATED DEPOSITS.

The unconsolidated mass of bowlders and gravel which flank the mesas at a few localities on the reservation are capable of holding large quantities of water. Samples from the alluvial deposits filling the larger washes were found to range in amount of pore space between 6 per cent for loess and clay silts and 40 per cent for coarse gravels. The average for all the alluvial materials examined is probably not far from 25 per cent of pore space in total volume.

METHOD OF FILLING THE GROUND-WATER RESERVOIR.

The vast underground reservoir, consisting of the aggregate void space in rocks and unconsolidated sediments, may be filled, partly filled, or empty, for the capacity of rock and soil to hold water by no means insures the presence of water. Like other reservoirs, water must be put into them if water is later to be taken out. Ground-water reservoirs are filled by percolation—that is, the tendency of water falling on a porous surface to pass downward to the surface below which the soil or rock is already saturated.

The percolating waters found within the ground may originate in one of several ways:

Directly from the rainfall.—The amount of rain water that passes into the ground is subject to wide variation. On steep slopes rain forms rills which carry the water away so rapidly that little opportunity is given for downward percolation. On surfaces of

gentle slope, and especially those with minor inequalities, such as sand dunes, rock pockets, and also on grass-covered areas, the rainfall remains on the ground long enough to find its way downward into cracks and pores. Where snow replaces rain the percentage of precipitation which enters the ground is still further increased. In some places the total precipitation is either absorbed or evaporated and none is left to form streams. On certain gravel slopes all the water contributed by a brief shower may pass directly into the soil. On the other hand, where rain falls on bedrock, percolation assumes low values and may not take place at all before evaporation and run-off remove the water from the surface.

Percolation from stream channels.—Perennial streams passing through arid districts lose water by percolation into the surrounding soil and rock. The same process is going on in intermittent streams and also in ephemeral streams. In certain localities on the reservation the major portion of the permanent ground water has its origin in streams.

Percolation from flood waters.—During the month of August, most of the great washes are at flood stage and the waters in the normal channels with slight or no flow at other times of the year spread hundreds and even thousands of feet beyond the valley axis. These waters percolate downward into the porous alluvium and become part of the ground water.

Of the three sources of ground water mentioned, percolation from stream flow appears to yield the greatest amount, followed in turn by direct precipitation and percolation from flood waters.

DEPLETION OF THE RESERVOIR.

PROCESSES OF DEPLETION.

Water that percolates into soil and rock and is stored in voids between the grains and in open cavities and in cracks and joints constituting the ground-water reservoir does not remain undisturbed, sealed beyond the reach of other agents. The reservoir is continuously drawn upon and tends to become depleted by soil evaporation, transpiration, evaporation from seeps, and discharge from springs.

In order that the processes whereby depletion is affected may be understood it should be remembered that water exists in the ground in two forms, "capillary water" and "gravity water." Capillary water occupies minute pores and forms thin films surrounding soil grains. It does not form part of the water that emerges as springs and it can not be recovered by means of wells. Some clays and fine silts may be saturated with water and yet yield no water to wells

sunk in these materials because the cavities containing water are all of capillary size. "Gravity water" occupies those open spaces in the rock and soil which exceed capillary size. The water is free to move among the grains, through the rock or soil, in any direction determined by gravity. "Gravity water" may flow from the rock as springs or find its way into holes dug for wells or, like capillary water, may be removed directly by evaporation.

EVAPORATION FROM THE GROUND.

The depletion of the ground-water supply is in large measure effected by evaporation from the upper surface of the reservoir. Evaporation is facilitated by high temperature of soil and of air and by dryness of air and by winds. In all these respects the climatic conditions of the Navajo country favor high evaporation, particularly during the summer months. The amount of moisture in the surface layers of the soil is also an important factor and depends on the capillarity of the soil and the depth to water. In fine-textured soils water may be drawn upward from a greater depth than in coarse-textured soils. The disastrous results of excessive evaporation as observed in the Navajo country have one compensating advantage. The loss of water in the upper part of the soil is so much more rapid than at points a short distance below the surface that a layer or mulch of dry soil is formed over moister portions beneath. The effect of this mulch of dry soil is to greatly retard evaporation. An understanding of this process explains the apparent contradiction that soils of arid regions taken a short distance below the surface may hold more moisture and retain the moisture longer than do soils of humid regions.

Over parts of the reservation the water absorbed by the ground and having its origin in precipitation is returned to the air before it reaches the permanent ground-water reservoir. After single showers, and twice after a month of rain estimated at 2 inches, it was noted that test wells sunk in the Tusayan Washes encountered water or damp soil at depths between 1 and 4 feet, below which zone the alluvial sands were dry to depths exceeding 20 feet. During June these same places showed no water from the top to the bottom of the drill holes. In the sand dunes about the Hopi villages water sufficient for corn and for peach trees is found in a narrow zone 4 to 6 feet beneath the surface. The sand is without moisture, both above and below this zone. C. H. Lee [1] found in Owens Valley that ground water to a depth of 8 feet below the surface was continually drawn upon by evaporation.

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[1] U. S. Geol. Survey Water-Supply Paper 294, 1912.

An undetermined portion of the soil water reaches the air indirectly through plants which absorb moisture at their roots and release it from their foliage by the process known as transpiration. The results of all experiments indicate that the amount of soil water consumed by a growing plant is very large. For example, in the production of a ton of alfalfa about 400 tons of water is used by the plant, and 200 to 300 tons of water is required to produce a ton of corn. An average for the ordinary farm crops is 325 tons of water to 1 ton of dry matter.[1] Though no figures are available for the Navajo country, it is probable that the amount of water transpired by plants during the growing season exceeds the amount directly evaporated.

EVAPORATION OF SPRINGS AND SEEPS.

Water issuing as springs further depletes the ground-water reservoir. Strong springs transfer certain quantities of ground water to the surface supply. Many springs, however, merely serve to bring ground water within the sphere of action of evaporation, thus decreasing the quantity of water available for man. The effect of evaporation on the flow of springs in this region, though not quantitatively determined, is readily observed. I have noted that in several springs yielding each a gallon or less a minute the flow during the night has nearly doubled, and my Navajo guides have pointed out places where springs that flow in dry but cold winter months cease to flow during the equally dry but warm summer months. Seeps show even more marked fluctuation in response to evaporation. In the early morning, before sunrise, wet spots were frequently observed on the face of sandstone ledges and occasionally were found to exude sufficient water for camp use. During the heat of the day, however, all trace of seepage may disappear. On one occasion our party reached a " spring " late in the evening, only to find it practically dry. To our great surprise sufficient water was flowing next morning for eight horses which had been 24 hours without water.

THE WATER TABLE.

The various processes at work to deplete the ground-water reservoir result in leaving it only partly filled. The water in the upper layers of rock or soil is in many places drawn off, so that the top of the ground water is therefore not at the surface of the ground, but stands at a variable distance below it. The top of the ground water is known as the water table. (See fig. 10, p. 124.)

Below the water table the ground is saturated; above it the soil or rock is relatively free from water except immediately after rain

[1] King, F. H., The soil, p. 156, 1908.

falls. The water table is not a horizontal plane, but roughly parallels the surface of the land, rising and falling with surface elevations and depressions. It reaches its highest elevations underneath hills and its lowest beneath valleys but is farthest from the surface on hills and comes nearest to the surface in depressions. At the margin of perennial lakes and streams the water table coincides with the surface-water level.

These relations may be better understood if we keep in mind the fact that ground water, like surface water, is under the control of gravity, which causes water to flow both underground and on the surface from the hills toward the valleys or washes. The movement of the surface water is unrestrained, and the water which falls as rain immediately runs from the highlands; but the movement of ground water is very slow, less on the average than a mile a year. Because of this slowness of movement streams may have constant flow, springs may yield water throughout the dry season, and in many places shallow wells may obtain water even on hilltops.

The position of the water table is determined by noting the level at which water stands in those wells which are unaffected by artesian conditions. Wells of this type, exceeding 50 feet in depth, have been dug or drilled in connection with the plans for developing water for the Navajo and Hopi Indians, and a few wells previously constructed are available for study. The wells are grouped in four localities—at Leupp in the Painted Desert, along the Tusayan Washes, in upper Chinle Valley, and on the southern margin of Chaco Plateau. For the remaining 70 or 80 per cent of the area under discussion no records are available. It has been found that wells sunk in the immediate channels of the larger alluvium-filled washes yield supplies satisfactory in quantity and in quality at depths of 10 to 20 feet and in many places less than 6 feet. On the flat slopes leading to the washes the water table is reached at depths between 50 and 60 feet. These figures, obtained from wells sunk in unconsolidated deposits along the Little Colorado, the Pueblo Colorado, and the Tusayan Washes, are probably applicable to similar situations throughout the reservation. In several places water is found at the top of the first rock stratum reached in digging the well.

For wells in rock the figures indicating the position of the water table have local application only, for the impervious or pervious character of the rock traversed and the number and opening of joints are subject to wide variation, even in neighboring localities.

The popular belief that certain trees and bushes indicate depths to water is not borne out by field observations. The distribution of vegetation with reference to depth of water table is, however, a topic of interest. Studies in Owens Valley, Cal., where the mean annual precipitation is less than that for the Navajo country, have shown

that fresh-water grass thrives where the depth to ground water does not exceed 3 feet; that in general grass is absent from areas where the water table is depressed below 8 feet. Sagebrush, greasewood, rabbit bush, and bunch grass survive where the water table lies 12 to 20 feet below the surface.[1] So far as fresh-water and salt-water grass and plants adjusted to alkali soils are concerned, the conditions on the Navajo Reservation duplicate those in Owens Valley; but sage and a variety of grasses and annuals grow about well sites, where the permanent water table lies 30 to 50 feet below the surface. Even the cottonwood, whose presence usually indicates a depth to water not exceeding 20 feet, is found growing in the lower Oraibi Wash at a spot where the water table is at least 50 feet below the surface. The explanation of these phenomena appears to be that a saturated zone produced by percolation rests, for part of the year at least, between the ground surface and the water table.

The fluctuation of the water table with the seasons and from year to year must be considerable, but the wells have been in existence for too short a time to give significant data.

QUALITY OF GROUND WATER.

No chemical studies have been made of the waters of the Navajo Reservation, but the following statements are believed to be of general application. Springs and wells observed in the Moenkopi formation except two, in Bonito Canyon and Box Springs, yield alkaline water. Water from this formation at Douglass Camp is unfit for man or beast. Most of the springs in the uppermost Triassic formation (Chinle) and in the Mancos shale are also unpalatable. Water from the Triassic shales at Chinle School is of such quality as to merit condemnation. Springs in other formations furnish supplies suitable for all purposes. Only about 2 per cent of the wells and shallow pits sunk in the alluvial fills of the washes were found to have water unfit for use.

ARTESIAN WATER.

The ground-water reservoir ordinarily is filled by percolation at or near the place where ground water occurs. The water, therefore, is not confined under pressure but moves more or less freely, and the water table rises and sinks in accordance with climatic changes in the immediate vicinity. There is, however, another ground-water storage reservoir in which the waters are not affected by climatic changes in the region immediately overlying them and may find their sources in regions many miles distant. Such waters are under pressure, being held by a cap of impervious material. When the

[1] U. S. Geol. Survey Water-Supply Paper 294, p. 77, 1912.

pressure is released by puncturing the roof of the reservoir, as by a well drill, the water rises through the impervious stratum which hitherto has confined it. The pressure may be sufficient to force to the surface the water from this deep-seated reservoir or may be only enough to cause a rise of a few feet. In either event the water is "artesian," for this term is applied to all ground waters that show an appreciable rise when struck, whether or not the pressure is sufficient to produce flows at the surface. In the Navajo country artesian water has been found on the Chaco Plateau and is believed to be present in Chuska Valley, the upper Chinle Valley, in the northern part of Gothic Mesas, and to a less extent elsewhere. Such areas are reserved for description in connection with a discussion of wells (pp. 176–183).

SPRINGS.

DISTRIBUTION AND CHARACTER.

One of the surprises that awaits the traveler in the Navajo country is the large number of springs widely distributed over the reservation. Tucked away in alcoves in the high mesa walls or issuing from crevices in the canyon sides or bubbling up through sands in the long wash floors, these tiny supplies of water appear to be distributed in haphazard fashion. Few of the hundreds of little springs yield more than a gallon a minute; some of them are charged with salts, and many of them are accessible only to a man on foot. Safe traveling in this region involves a knowledge of the location of these springs, and exploration consists essentially in directing one's course from spring to spring. The ancient cliff dweller was well aware of the desirability of these small permanent supplies as centers for settlement, and many of the present-day Indian trails owe their position to the location of springs rather than to topography or to length of route.

The chief reason why the springs of the reservation are so clearly defined is the boldness of the topography. Valley floor meets canyon wall or mesa face or mountain border abruptly. High walls of bare rock in many places join the alluvial fill of washes at angles approaching 90°. There is a singular absence of talus and of fans flanking the highlands. Springs therefore emerge directly from rock walls without the intervention of a cloak of sands, gravels, and bowlders, which tend to conceal the opening by which ground water leaves the rock. Also the recent cutting of the floors in alluvium-filled canyons has exposed the point of emergence of water formerly hidden from view. An additional reason for the individuality of springs is their more or less complete separation from the perennial drainage and their independence of the short-period fluctuations in rainfall and

ephemeral stream flow. In general the springs flow from a definite spot rather than from an undefined area of swamp, and their waters rarely extend far from the exit.

Nearly all the springs on the reservation are of the normal type—that is, they mark points of escape of ground water which has entered the rock or alluvium at higher levels and found its way downward and outward through cracks, between grains, and along bedding planes. A few springs are artesian in character and reach the surface only after finding an opening in impervious beds through which the water is forced upward by pressure exerted at some distant locality. The Boiling Spring (Navajo, Tohalushi) in Laguna Canyon and the Mud Springs at Tuye on the Chaco Plateau illustrate flows which escape under pressure from retaining beds of clay and silt.

With respect to mode of origin the springs of the Navajo country may be grouped in five classes, namely, springs in unconsolidated materials, springs between ledge and alluvial cover, springs emerging from the contact of two rock strata, springs within a single stratum, and springs emerging from fault lines.

SPRINGS IN UNCONSOLIDATED DEPOSITS.

GENERAL RELATIONS.

Springs issuing from unconsolidated deposits are found in the bottoms of the main washes and their tributaries, on slopes buried with talus, or within materials of alluvial fans. An alternation of porous and relatively impervious layers is essential, otherwise the percolating water tends to sink downward to join the permanent ground-water reservoir from which it may be recovered only by means of wells. The most favorable arrangement is a series of beds of clay and adobe interstratified with sands or gravels—a series of strata whose edges are exposed by erosion. Springs of this type emerge on flat or sloping surfaces, or directly from alluvial walls bounding arroyos, and their presence is indicated by bogs or by areas of sand through which water bubbles continuously or intermittently in response to precipitation and evaporation. In many places the water feeding the spring is held near the surface; elsewhere the water-bearing bed lies some distance below the surface and the outlet slopes obliquely upward, traversing porous lenses in the alluvium.

At St. Michaels two short canyons with numerous tributaries unite to form a wash whose floor is so thoroughly saturated with water that native grass has a luxuriant growth. This is the well-known meadow Cienega Amarilla. From the walls of arroyos in the meadow springs issue at a definite horizon between coarse and fine sands. (See Pl. XXVI, *B*, p. 111.) The supply from these springs

and from shallow flowing wells in the garden is sufficient for the uses of the large school conducted at this place. Similar conditions have given rise to Manuelito and other springs within Chuska Valley, where layers of adobe underlie deposits of gravel and of wind-blown sand. In Segihatsosi Canyon, where the terraced valley fill is 40 to 50 feet deep, many springs emerge from the alluvial strata at the base of the lower terraces and also from the arroyo walls. Near Fluted Rock several springs emerge from the alluvium of the flat-floored valleys. Awatobi Springs form the outlet for waters confined in alluvium and dunes which cover the canyon floor. Because of their relatively large flow (6 to 10 gallons a minute) the springs at this place have served in turn as a center of residence for cliff dweller, Hopi, and Navajo. The springs about the flanks of the Hopi Mesas and the War God Spring on Navajo Mountain are examples of outflows of water confined in talus and landslide materials.

METHODS OF IMPROVEMENT.

The purpose of development of springs is twofold—to increase the available supply and to improve the quality of water for domestic uses. In respect to both these purposes the springs on the reservation are susceptible of great improvement. When my studies were begun in this region (1909) probably not more than a dozen springs had received proper attention. During the last few years much work has been done by the Indian Office, particularly on the Hopi Reservation, and in imitation of the white man's work the Indian has undertaken development on his own account. Under the guidance of Government officials the condition of springs throughout the entire Navajo country will probably be much improved during the next decade. No spring can be said to be fully developed until a large part of its flow is recovered, provision is made for the storage of surplus waters, and part, at least, of its waters has been protected from contamination. Under present conditions few springs recover more than 50 per cent of the flow, many of them less than 10 per cent, and several springs capable of furnishing 1 to 3 gallons per minute are represented by useless seeps or areas of moist sand. Many of the springs are in a filthy condition, and the droppings of stock and of wild animals not uncommonly are included in the water used by man.

For springs and seeps in unconsolidated materials on valley floors or gentle slopes the simplest method of development is to sink boxes of wood or tile or cement at the point where water emerges most freely from the ground. These boxes should have a large cross section, perhaps 10 or 15 by 5 feet, and should be set at right angles to

the immediate slope of the surface. They should be tightly covered to retard evaporation and to prevent contamination, and water for stock should be piped to troughs or basins at lower levels. It is highly desirable to have some method of shutting off the flow when water is not being used. At a few places the Navajos have excavated holes, cribbed them with cedar poles, and led the overflow through ditches to pools. The method is correct, but the loss from evaporation and soil absorption could be greatly reduced by substituting covered concrete boxes, iron pipes, and cement or wood troughs. In those places where seeps or springs occur within arroyos subject to flood it is usually advisable to sink a well on the bank to a depth below the point of emergence of the spring. The supply yielded by springs that emerge on talus slopes, on landslides, and on the steeper parts of alluvial fans may in many places be greatly increased by constructing tunnels and galleries. (See fig. 11.)

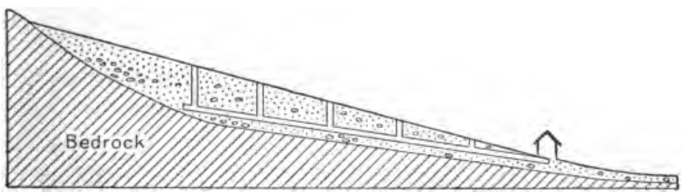


FIGURE 11.—Diagram illustrating method of constructing a kariz.

The spring or seep determines the heading of the tunnel, which should be projected backward into the loose material with a slight upward slope. The length of such tunnels may be limited only by the rock slope encountered, and groups of lateral galleries may be provided. In Persia and Turkestan, where, under the name "kariz," such horizontal wells are in common use for stock and for irrigation, the galleries are not uncommonly several miles long. The method of construction adopted in Persia is to sink shafts at intervals of 100 to 200 feet along the axis of the kariz. From the bottom of each shaft the tunnel is driven in both directions. The Persian practice is to leave the tunnels and shafts open and to clean out each year the material which slumps into the kariz. An equally satisfactory method, and one which would obviate the annual cleaning would be to fill the tunnels and laterals with cobbles, through which the water could circulate freely.

In developing springs in unconsolidated materials it should be remembered that strata of silt, gravel, sand, and clay are rarely continuous for more than 100 feet—at most a few hundred feet—and that therefore it is seldom possible to determine accurately the extent of the underground reservoir or the quantity of water available.

SPRINGS BETWEEN ALLUVIUM AND BEDROCK.

GENERAL RELATIONS.

In contrast with soils, sand dunes, and the filling of the washes bedrock retards the downward percolation of water; in fact, some types of rock, particularly shale, are so impervious as to prevent it. The top surface of rock ledges buried under unconsolidated materials becomes therefore in many places a water-bearing horizon of considerable importance. Where conditions are favorable water finds its way along the rock surface and emerges as springs. The permanence and yield of springs of this origin depend on the amount of water stored in the overlying sands and gravels, the degree of permeability of the underlying rock stratum, and the extent to which evaporation succeeds in depleting the supply. In the Navajo country springs issuing between bedrock and alluvial cover occur most commonly in two situations—in rock-floored, alluvium-walled canyons and in shallow flats adjoining areas where wind-blown sand combines with stream deposits to form a good collecting area. At the base of alluvial banks in the recently cut inner canyon of the Tyende springs issue along the rock surface at a number of places and for stretches of hundreds of feet a continuous line of seeps may be observed. In Black Creek Valley, at Hunter Point, and at Oak Spring the top of the ledge beneath the alluvium is coated with a film of water. At White's trading post, where the water table is 20 feet below the surface, water emerges as springs on top of a rock ledge and continues to flow throughout the dry season. Coyote Springs, near Pyramid Butte, consist of seeps extending along a shallow wash for a distance of 300 to 400 feet. The overlying beds are lenticular masses of gravel, sand, and adobe and the beds below are red shales. At Chandler ranch the rainfall is collected on a low mesa covered with wind-blown sands overlying coarse alluvium, which in turn rests on shales. A seepage line marked by grass and "water bloom" extends with interruptions about 1,000 feet along the mesa wall. Excavation at one point produced a flow of 1½ gallons a minute where previously only seepage reached the surface. The large Tanner Spring and its smaller companions emerge at the top of shale ledges and the supply at Tyende has a similar origin.

METHOD OF DEVELOPMENT.

In planning improvements for springs issuing between alluvium and bedrock it should be borne in mind that the ground water forms a thin sheet of great horizontal dimensions; that a zone of seepage marked only by damp soil or a narrow band of luxuriant vegetation may represent flows of considerable volume, now checked by evapora-

tion. The object of development is to collect at one point the waters now widely distributed. Various methods have been devised to accomplish this purpose.

At Coyote Spring a box is sunk into the ground at the point of greatest flow. At Chandler ranch a basin is excavated in the rock below the zone of flow. At Tyende a ditch has been dug along the line of seepage and the water directed into reservoirs at lower points. Comar Springs flow from the contact of rock with coarse sand and volcanic ash. The porosity of the surface material and the large collecting area cause the strong flow at this point.

Where the unconsolidated deposits are not too thick, subsurface dams of board, clay, cement, or other impervious materials, placed either at right angles to the direction of underground flow or built in the form of a broad V may be constructed. A tight contact between dam and rock and an outlet for the water are the only requisites. Where the materials are of such nature that water percolates slowly, ditches filled with bowlders, among which water may pass freely, may be substituted for the subsurface dam. Where the rock consists of talus or slide débris the extent of the film of water is difficult to determine. For such places the supply may be increased by digging a ditch or driving a tunnel directly into the hillside at the point where the largest amount of water emerges, and constructing laterals leading from it. The ditch may be covered or filled with cobbles. By this method the outlet is brought nearer the chief supply, and the heads of a number of small seeps may be combined into one flowing stream. The water supply at Sunrise Spring (Navajo, Kaiso-an, place where trees have been set out), at Indian Wells, and at Maddox (Stiles ranch) illustrate the successful application of this principle. If a large amount of water is desired the rock ledge may be followed back for hundreds of feet and a kariz constructed as was recommended for springs in unconsolidated materials. (See p. 135.)

Where the unconsolidated materials overlying rock are relatively thin, the construction of a well back of the zone of seepage may be found less expensive than the excavation necessary to develop the spring.

SPRINGS BETWEEN ROCK STRATA.

GENERAL RELATIONS.

Springs at the contact between strata of solid rock constitute the largest and most valuable source of water in the Navajo country. They range in yield from mere seeps to 20 gallons a minute, and are least liable to fluctuation of all the classes represented. Like springs issuing between rock ledge and cover of unconsolidated

material, their position is determined by the relative permeability of strata, and the amount of water recovered by them depends on the extent and character of the collecting area, the porosity of the overlying rock, and the tightness of the underlying beds. The quality of water depends on the composition of the strata through which the rain finds its way downward. The beds of high porosity through which water may pass with relative ease are the sandstones; shales and limestones, on the other hand, serve to intercept percolation. In the sedimentary rocks of the Navajo country there are seven well-marked spring horizons.

1. The contact between the Moenkopi formation and the Shinarump conglomerate. The conglomerate is more or less pervious and is broken by numerous joints. The water escapes downward until intercepted by shales or fine sandstones. The plane on which the film of water rests is irregular, and the incipient channels formed lead in most places to definite outlets rather than to lines of seepage. The water is invariably of good quality, as shown by Janus Spring, Tucker Springs, and the springs about 4 miles east of Agathla.

2. The contact between the Chinle formation and the Wingate sandstone. The sandstone possesses high porosity; the shales and limestones of the Chinle are much less pervious. The water from this source is of excellent quality.

3. The contact between the Todilto formation and the Navajo sandstone of the La Plata group. The Todilto limestone, the middle formation of the La Plata group, is not everywhere present, but where it occurs it constitutes a stratum that is unusually water-tight. The overlying Navajo sandstone imbibes water freely, and the wide exposures of this formation make it one of the chief water carriers of the region and one from which water of excellent quality may be obtained.

4. The contact between the McElmo formation, of fine sandstone and shales, and the overlying Dakota sandstone which is noted for its porosity. The springs of the Steamboat Canyon district and those near Bitsihuitsos Butte illustrate this class. The supplies from this horizon range in quality from water adapted for all purposes to that with a fairly high content of iron.

5. The contact between the Mancos shale and the sandstones of the widespread Mesaverde formation. Water of good quality issues from this horizon at 30 or 40 springs about the edge of the Black Mesa and at other localities where Cretaceous strata are represented. The agency and schools at Keams Canyon and in part the Hopi villages are supplied by springs of this type.

6. The contact between the Chuska sandstone and the underlying Tohachi shale. (See pp. 140–141.)

7. The contact between the lavas and ash of the Hopi Buttes region and the underlying sedimentary rocks. (See below.)

Water also issues in a few places between strata forming parts of a single formation. Half a dozen springs are found between the sandstones and shales within the Moenkopi formation. One of these, Box Springs, on the Little Colorado, yields water of satisfactory quality, but most of the springs of Gypsum Valley are highly charged with alkali. The Chinle formation and the Mancos shale likewise are represented by a few springs, but the quality of the water recovered is such as to render them of little value. The Mesaverde formation, on the other hand, is composed of a series of sandstones and shales and has within itself the requisite conditions for the production of a few springs, both of pure water and of water charged with sulphur.

SPRINGS OF THE HOPI BUTTES PROVINCE.

The Hopi Buttes embrace a group of volcanic necks and of lava-capped mesas which rise sheer above the flat-floored washes at their base. The mesa caps range in size from a few acres to the large central area of partly connected tables, Hauke Mesa, nearly 100

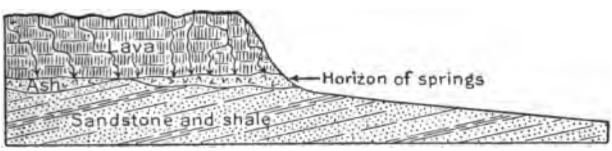


FIGURE 12.—Diagram illustrating the conditions producing the springs in the Hopi Buttes region.

square miles in extent. The mesa sides are made up of sandstone and shales of various ages; their tops are formed by sheets of lava 20 to 100 feet thick. Within the lavas and in certain localities beneath them are beds of volcanic ash and of tuff. The surface of the lavas is roughened by pits and cracks and shallow depressions which retain the rainfall to a large degree and direct it downward instead of outward through established drainage channels. The circulation of water within the mesas follows therefore a simple plan. The rain percolates into and through the porous and fissured lava, into the ash, only to be arrested by the more impervious sedimentary strata below, along which it passes to the mesa edge (fig. 12). The result is a series of springs emerging at the base of the lavas, springs whose volume is directly related to the size of the lava field from which their supply is drawn. The large central mass produces many springs, the smaller groups of mesas have fewer springs with less total yield, and most of the isolated mesas an acre or two in surficial extent have one or more tiny springs or seeps (fig. 13).

At the old Stiles ranch (Maddox) there are three sets of springs flowing, respectively, 2, 4½, and 5 quarts a minute, as measured in June, 1909. They all emerge from the base of the lava. At Cottonwood Spring the water escapes from an ash bed at its contact with underlying shale; at Cedar Springs about a gallon a minute is recovered from tuff. At Lokasakad the water from the lava contact passes into the soil and emerges as a bubbling spring yielding 8 to 10 gallons per minute. At Indian Wells water is recovered by a group

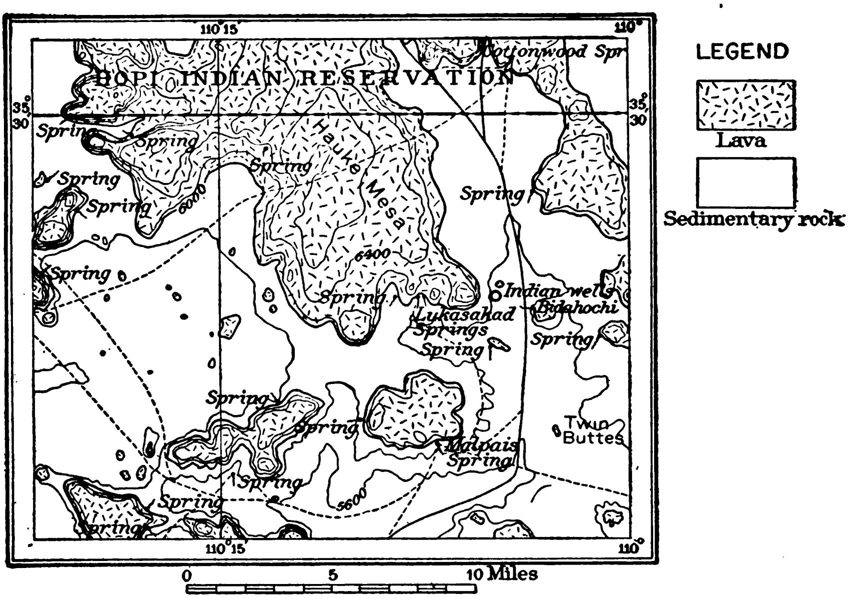


FIGURE 13.—Map of a part of the Hopi Buttes province, showing the distribution of lava and sedimentary rock with reference to the position of springs.

of shallow pits and tunnels sunk in an alluvium-filled swale between lava cliffs, but its ultimate source appears to be the contact of the lava and the sandstone.

SPRINGS OF CHUSKA MOUNTAIN.

Along the eastern front of Chuska Mountain, at an elevation of about 8,200 feet, a rough-floored terrace extends for several miles. The inner edge of the terrace is marked by cliffs of sandstone 200 to 500 feet high; its outer edge is littered with landslide débris and breaks off by a series of steps to join the lower slope of the mountain. The terrace is occupied by prosperous Navajo farmers whose fields are well watered by springs that emerge at the base of the precipitous sandstone wall. I am informed that 11 of these springs are utilized for irrigation and that there are more than 30 springs at this horizon between Tohachi and Washington Pass. The largest

of these springs observed by me is Nikehoshi (Navajo: One eye; named after the self-styled owner), which issues at two points and

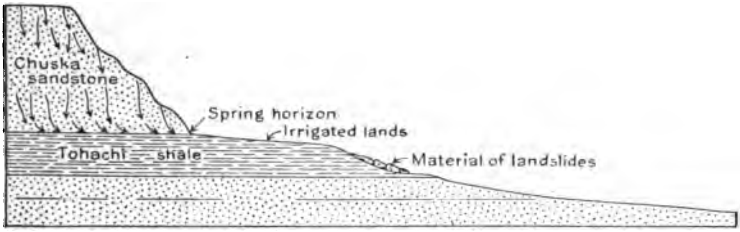


FIGURE 14.—Diagram illustrating the conditions producing springs on the east flank of Chuska Mountain.

yields 30 gallons a minute. About half this amount is utilized in irrigating fields for 14 Navajo families (fig. 14).

METHODS OF IMPROVEMENT.

Plans for increasing the flow of springs emerging between rock strata involve the following fundamental considerations. The water resting on the impervious bed forms a thin sheet of large dimensions; the porous bed above is more or less saturated with water; water percolates outward from the face of the rock as well as downward to the confining bed; springs and seeps and wet rock surfaces, as well as rock faces, moist only during the night, may derive their

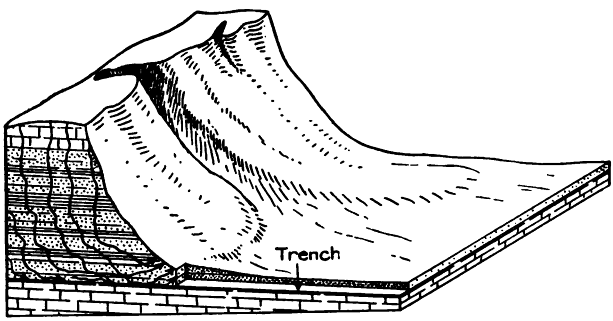


FIGURE 15.—Diagram illustrating method of combining several small scattered flows from rock.

waters from a common source, and all tend to deplete the supply; the amount of water evaporated from heated rock faces may equal the flow of a spring of moderate size.

The purpose of developing springs of this class is to recover all the water possible from a given length of cliff line, to convert a series of seeps and small springs into one large spring, and to reduce the amount of water lost by evaporation. One method of accomplishing this result is to drive a tunnel into the water-bearing strata, using

the top of the impervious bed as the floor of the tunnel. Lateral drifts from the central tunnel would recover water otherwise lost by evaporation. Another method is to construct a covered ditch along the rock face at the level where seeps occur in order to combine several small supplies into a single larger one. Open trenches may give satisfactory results, but a large loss from evaporation must be expected.

An unfailing supply has been obtained at Tucker Springs by tunneling beneath the conglomerate forming the cap of a local mesa and the only reliable supply of water between Gallup and Fort Defiance is obtained from a series of tunnels about 150 feet long driven along the contact between strata of shale and of sandstone. At Burro Springs, which makes the Winslow-Oraibi road feasible for travelers, tanks have been sunk in the rock at the base of porous sandstone. A cover of poles protects the supply not only from stock but from rapid evaporation. At Lizard Spring, about 6 miles north of Ganado, a trench 20 feet long and 1 foot to 10 feet deep would convert several tiny springs into a satisfactory supply. (See fig. 15.) The yield of the spring at the Lower Crossing of Piute Canyon could probably be increased to 60 or 80 gallons per minute by a shallow rock trench 500 feet long. The springs at Keams Canyon, Wepo, Howell Mesa, Hopi Buttes, Monument Valley, Moonlight Valley, Tyende, and other localities are susceptible of improvement by inexpensive ditches and tunnels.

Of the many springs issuing between rock strata none were observed which yield their maximum supply; 25 to 50 per cent of the water is recovered from about half of the springs now utilized, and at several places noted the entire flow is lost by absorption in sands. This proportion of water recovered to the amount available holds true of all classes of springs on the reservation. At a point on Carson Mesa a few minutes' digging in wind-blown sands resulted in exposing a water horizon in rock from which a flow of a gallon a minute was obtained. On the west slope of Tunitcha Mountain, Lieut. Gurovits reports that by digging with branches broken off trees the flow of a spring was increased from about 30 quarts a minute to 16 gallons a minute.[1]

SPRINGS WITHIN A STRATUM.

The water stored within the massive beds of sandstone may find its way to the surface before reaching an impervious layer below. The Navajo sandstone in particular gives rise to numerous springs of this sort. The water emerges between cross-bedding laminæ on oblique or curved or horizontal planes and at a few places—for example, at Tunnel Springs—has enlarged joints and interstratum

[1] 52d Cong., 2d sess., Ex. Doc. 68, p. 20, 1893.

spaces into alcoves and tunnels large enough to allow the entrance of a man. Sixteen springs issuing from the sandstones of the La Plata group and yielding from half a pint to several gallons a minute of clear, pure water were utilized by members of my party for camp supplies; and more than 100 tiny seeps in the Navajo sandstone were found hidden away in alcoves and under shelves, many of them in places difficult of access. On one occasion disaster was averted by the knowledge that seeps may be found on the sheer bare walls of dry-floored canyons carved in cross-bedded sandstones. Springs of this type may be developed by artificial tunnels driven along the water-bearing contact in accordance with the plan suggested by the natural openings.

FAULT SPRINGS.

Many springs of all classes utilize joints within the rocks, and the underground flow of some springs is greatly facilitated by the presence of open fissures, along which water finds its way. Fault springs are, however, rare, for faults with a throw of more than a few feet are recorded for less than a half dozen places on the reservation. In fact, the only spring noted which unquestionably has its origin in a fault zone is found in Junction Canyon, at which place 1 gallon of water a minute issues from a fault of 6 feet displacement in the Navajo sandstone.

SPRINGS OF THE TUBA DISTRICT.

GENERAL RELATIONS.

Tuba is a veritable oasis—a patch of green in the midst of a most forbidding desert. Surrounded on all sides by stretches of bare red rock, across which dunes are continually driven by southwest winds, this spot has been the seat of an agricultural population since times long antedating the discovery of America. The Spanish padres found the ancestors of the present Hopis cultivating cotton and corn in fields centuries old; explorers of later days have known the spot, and its advantages were recognized by the Mormon pioneers. About 1878 a group of Utah Mormons made their way across the Colorado and established a permanent settlement on this site, which, under the guiding hand of these skillful irrigators, soon reached a high stage of cultivation. The Mormon colonists who replaced the Hopi and Navajo were in turn replaced by Government officials, who have made Tuba the administrative and educational center of the Western Navajo Reservation. One giant spring, with a smaller companion, is the reason for the position of Tuba itself, but more than 30 additional springs account for the presence of fields and homes in the vicinity. Tuba may be said to rest near the edge of a table, two

sides of which are marked by cliffs from whose base emerge springs a short distance apart; a third side is a canyon, through which flows a spring-fed brook; on the fourth side, the north, an unbroken desert reaches the very edge of the irrigated fields.

The positions of the springs of the Tuba district are indicated on the maps (Pl. XXVII and fig. 16), which in slightly modified form are those kindly furnished by H. F. Robinson, superintendent of irrigation for the Indian Office.

The discharge of the springs is shown by the following table:

Discharge of springs of the Tuba district.

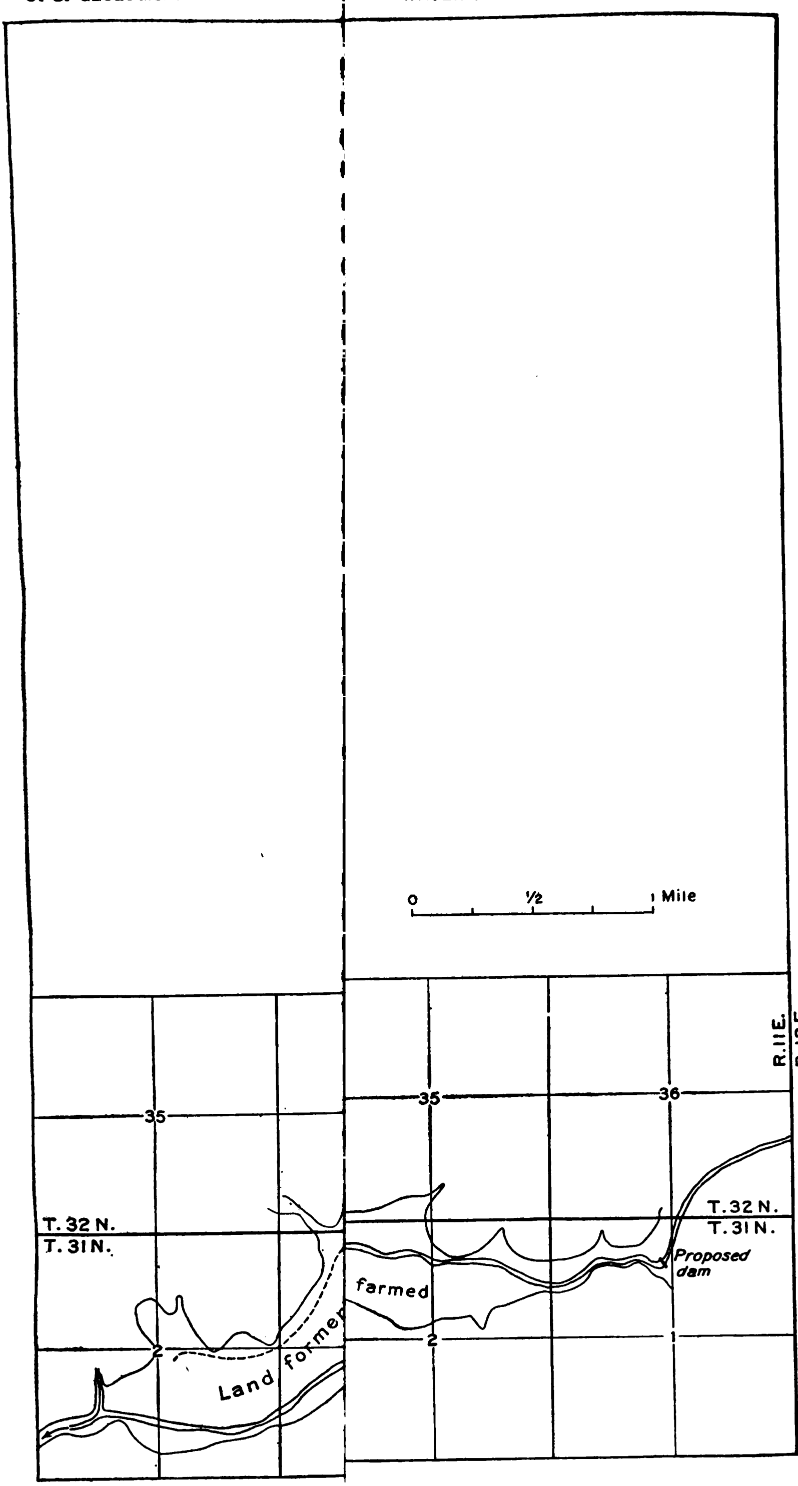
[Observer, R. Ritter.]

Name.	Discharge.		Date of record.	Remarks.
	Gallons per minute.	Second-feet.		
Springs on the Tuba school grounds:				
A	44.8	0.1	May, 1908.	The combined flow of A, B, and C as given by Ritter in 1908 was 80.6 gallons per minute. Robinson, measuring the two large springs, probably A and B of Ritter, reports a combined flow amounting to 112.5 gallons per minute (1914).
B				
C	35.8	.08	...do......	
Springs in Reservoir Canyon	224.4	.5	...do......	
Springs along Echo Cliffs:				
Moa Ave Spring	72	.16	...do......	
Lyon ranch	25	.055	...do......	Combined flow of springs from east and south.
Willow Springs	42	.093	...do......	Combined flow of all springs at this place.
Other springs	79	.17	...do......	Combined flow of all other springs within the Echo Cliffs area.
Springs in Moenkopi Wash	100	.20		Not measured; estimate based on the statement that "the flow from these springs is about half that from Reservoir Canyon."
	623	1.36		

ORIGIN OF THE SPRINGS.

In unpublished reports on file in the Indian Office and the Forest Service the springs of the Tuba district are stated to have their origin in faults which are assumed to outline Echo Cliffs and to traverse the Government school grounds. This hypothesis was kept in mind during my brief examination of this area, and step faulting on a minute scale was noted at Moa Ave; but no faults of more than a few inches displacement—faults of a type found in the sandstones at many places on the reservation—were observed. The stratigraphic succession—massive, cross-bedded Navajo sandstone overlying thinner bedded sandstones and arenaceous shales—is esssentially unbroken, and the arrangement of beds is apparently identical with that south of the Moenkopi Wash.

The massive cross-bedded sandstone, as well as thin strata of shale and sandstone, are, however, traversed by joints, in many places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½
1 Mile
R.11E.
R.12E.
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Proposed
dam
Land formerly
farmed
2
2
1

open, and there is a well-marked plane of separation between the laminæ of cross bedding in the Navajo sandstone. At Moa Ave, Lyon ranch, and the Government farm the water issues from the base of a 100-foot cliff of sandstone at its contact with red shales. At Willow Springs and in Reservoir Canyon the water emerges from joints and at the junction of two sets of cross-bedded strata, and the big School Spring appears to have the same origin.

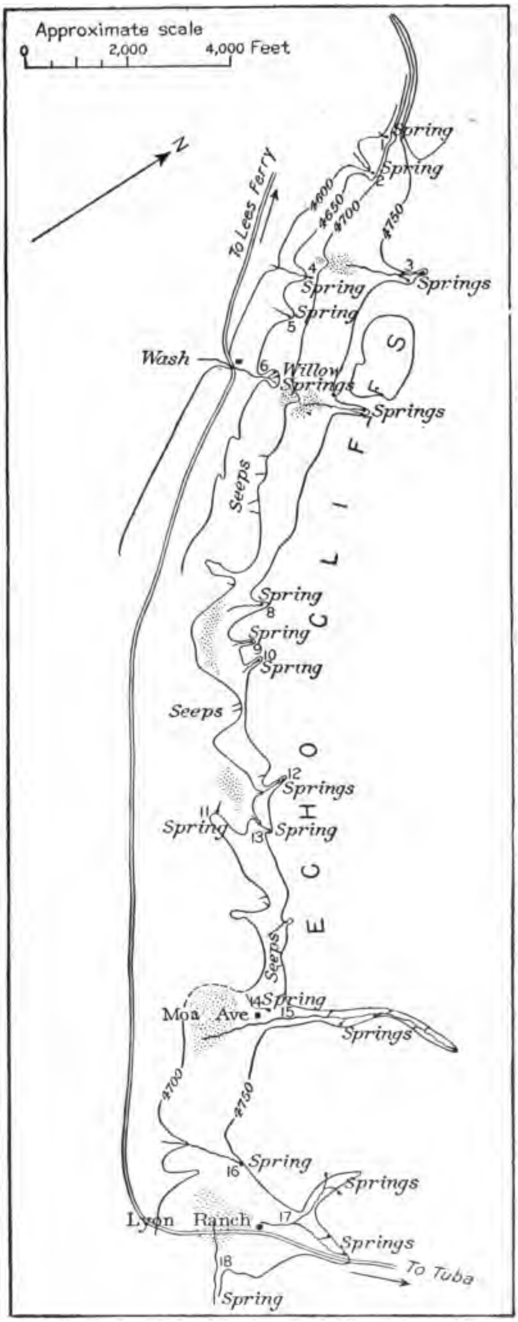


FIGURE 16.—Map of Echo Cliffs between Lyon ranch and Willow Springs, showing distribution of springs.

The geologic structure favorable for the accumulation of ground water at Tuba is as follows: The Navajo sandstone, which forms the surface rock on Kaibito Plateau, has high porosity, and its surface is so completely occupied by wind-scoured depressions and irregularly placed dunes that run-off is almost entirely prevented. Tuba is situated on the western limb of a flat syncline at a point where the dips of 15°± shown in the northern Echo Cliffs flatten to 3° and then to 1°. Moreover, the axis of the syncline pitches south-

ward toward Moenkopi Wash. The consequence is that water falling on a well-displayed collecting basin is imbibed by rocks of high water-holding capacity and is directed southward and southwestward by the structural arrangement of the sedimentary beds (fig. 17).

At first sight it would appear that the precipitation on the Kaibito Plateau is insufficient to supply the numerous springs in the vicinity of Tuba. If, however, we assume that the catchment area for the spring waters is the portion of the Kaibito Plateau which slopes toward the Moenkopi and that the average annual rainfall is 5.30 inches, the amount for Tuba, we find that 93,000,000,000 gallons of water falls on the collecting area each year, sufficient to provide for a flow of 170,000 gallons a minute. As the conditions for absorption are unusually favorable, and as the combined flow of the springs

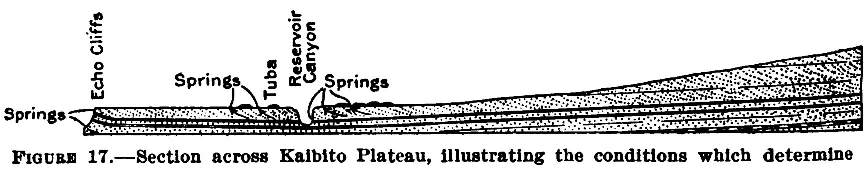


FIGURE 17.—Section across Kaibito Plateau, illustrating the conditions which determine the distribution of springs at Tuba.

in the Tuba district is only about 623 gallons a minute, it is obvious that no distant or deep-seated source need be ascribed to the springs of the Tuba district.

METHODS OF IMPROVEMENT.

None of the springs along the 7-mile stretch from Lyon ranch to Willow Springs are utilized to their full capacity. The water emerges as strong flows but is soon absorbed by the sand. At Lyon ranch are several undeveloped seeps in addition to four good springs. The water from one of these springs flows at the rate of 1½ gallons a minute but is lost in sand within 200 yards of its source. At this place, at Moa Ave, and, in fact, at all the springs issuing from the base of Echo Cliffs, the available supply could be increased perhaps 100 per cent by constructing concrete reservoirs at the point of greatest flow and adding to this supply the flow of adjoining seeps by a series of covered ditches. The construction of tunnels and galleries would further increase the yield. At the Government farm a concrete reservoir 25 by 27 by 6 feet has been constructed at a spring on the cliff slope, and the water delivered by 3,000 feet of 1¾-inch pipe. A similar plan has been followed at the Moenkopi Mission and may serve as a guide in developing other springs feeding directly into the Moenkopi Wash. The water from three large springs and several seeps in Reservoir Canyon is impounded by dams. This canyon is doomed to extinction by filling with wind-blown sand. The time is ripe for completing the system of galleries and tile drains

and stone culverts on and below the present floor of the canyon and leading the combined flow of all the springs to fields in the wash below. If this is done the obliteration of the canyon by filling will work no injury and may result in increasing the supply by retarding evaporation. The combined flow of the springs in Reservoir Canyon is placed by Mr. Ritter at one-half second-foot, or 224 gallons, a minute, a most important supply available for use in addition to, or as a substitute for, the mud-laden flood waters of the Moenkopi. The three springs on the Tuba Agency grounds have a combined flow, as measured by Mr. Ritter, of 0.18 second-foot, or nearly 80 gallons, a minute, about half of which issues from the School Spring. The water is impounded by a series of reservoirs and used to irrigate about 40 acres of field and orchard but is allowed to go to waste during five months of the year, when water is not needed for crops. Ten to eighteen per cent of the discharge from springs on the school grounds is lost before reaching the reservoir. It is estimated that by means of a properly constructed storage system water may be recovered in sufficient quantity to irrigate 100 to 125 acres in addition to supplying the school with an adequate amount.

SPRING RECORDS.

The springs listed in the following tables include most of those visited by members of my party during the years 1909, 1910, 1911, and 1913. Mr. George A. Keepers, allotting agent, has kindly furnished the location of springs for Tps. 23 and 24 N., R. 21 E., and at other points in the southern part of the Hopi Buttes area. Mr. J. W. Bush, acting agent at Leupp, has also taken pains to furnish a list of springs, arranged by sections, part of which has been used in the tables. To Mr. Matthew M. Murphy, allotting agent, I am indebted for the precise location of 21 springs in the Tusayan Washes province. Information regarding many springs has been obtained from Navajos and Hopis and from traders and Government officials. The list is, however, incomplete and doubtless contains errors due to misinterpretation of the statements of the Indians and to other causes. Moreover, with the base map used, all locations are necessarily approximate.

The springs were visited at various times, and few of them were seen more than once. Some of them were measured during May, June, and the first part of July, the dry season; and others after the annual rains had begun. The records obtained have, therefore, only qualitative value. The yield of the springs at Tuba was measured by engineers of the Indian Office; on the other hand, the flow of certain springs not visited by members of my party has been estimated from statements made by Navajo guides.

In the accompanying tables the springs are arranged by geographic provinces (see Pl. I, in pocket), as follows: Nos. 1–10, Dutton Plateau; 11–12, Chaco Plateau; 13–40, Chuska Valley; 41–62, Chuska Mountains; 63–65, Manuelito Plateau; 66–69, Black Creek Valley; 70–93, Defiance Plateau; 94–120, Pueblo Colorado and Chinle Valley; 121–159, Hopi Buttes; 160–169, Tusayan Washes; 170–225, Black Mesa; 226–228, Moenkopi Plateau; 229–239, Kaibito Plateau; 240–245, Rainbow Plateau; 246–247, Navajo Mountain; 248–249, Shato Plateau; 250–258, Segi Mesas; 259–262, Monument Valley; 263–267, Gothic Mesas; 268–276, Carrizo Mountain; 277–283, Painted Desert.

Records of springs in the Navajo and Hopi reservations.

No.	Name.	Location.	Source.	Estimated flow (gallons per minute).	Quality.	Remarks.
1	San Antonio Spring	Thoreau and Crown Point road	From alluvium or rock	5	Good	Perennial.
2	Tohasged Spring	12 miles northeast of Gallup, in canyon at northwest edge of Dutton Plateau.	Contact of sandstone and shale in Mesaverde formation.	.05	Slightly alkaline.	
3	Ojo Azufre	1 mile west of Pueblo Bonito				
4		Head of canyon 2 miles east of Midget Mesa	Sandstone at contact of alluvium and bedrock.	1	Fair	
5		In canyon at northwest edge of Dutton Plateau	Contact sandstone and shale in Mesaverde formation.	.03–2	3 slightly alkaline; 2 fair.	1 spring in each of 5 canyons.
6		1½ miles northeast of Pyramid Rock				
7		3 miles southeast of Jesus Lake				
8		Dalton's store				
9		In canyon 3 miles east of Dalton's store				
10		North end of Satan Pass				
11	Pintado Spring	10½ miles northeast of Pueblo Bonito Agency				
12		13 miles southwest of Simpson's store				
13	Manuelito Spring	7 miles southeast of Tohachi School	Contact of alluvium and Cretaceous shales.	.01–1	Good	A group of several springs.
14	Tuye Spring	16 miles south of east of Tohachi School	Alluvium at head of a wash	7	Fair	
15	Sheep Spring	2 miles northwest of Manning's store				
16	Sulphur Spring	15 miles north of Sheep Spring			Sulphurous	
17	Cottonwood Spring	Southeast of Carrizo Mountain	Contact of alluvium and Wingate sandstone.	.15	Good	
18	Vento Spring	8 miles northwest of Redrock store	Shales in Chinle formation			
19	Tisnasbas	Store north of Carrizo Mountain	Sandstone in McElmo formation	.50	Good	Perennial spring capable of development.
20	Mission Spring	Carrizo Mission, north of Carrizo Mountain	do	.50	do	Perennial; piped to house.
21	Biltabito Spring	Trading post, northeast of Carrizo Mountain	do	.50	do	Perennial; water held in cement tank.
22	Rock House Spring	Tisnasbas-Shiprock road, 12 miles east of Tisnasbas store.	Bedding planes within Mancos shale	1	do	Perennial; used for irrigation.
23	Mud Spring	7 miles southwest of Shiprock School			Sulphur	
24	Dike Spring	7 miles south of Shiprock School and on road to Gallup.				
25		5 miles south of Sheep Spring		(a)	Alkaline	Reported by Lieut. Brown.
26		4 miles south of Sheep Spring			Very alkaline.	Do.
27		1 mile northwest of Sulphur Spring			Sulphur	2 springs.
28		4½ miles west of Redrock store	Shales in Chinle formation			

a Small.

NOTE.—Dutton Plateau, 1-10; Chaco Plateau, 11-12; Chuska Valley, 13-29.

Records of springs in the Navajo and Hopi reservations—Continued.

No.	Name.	Location.	Source.	Estimated flow (gallons per minute).	Quality.	Remarks.
29		1½ miles west of Vento Spring	In Wingate sandstone			
30		On Shiprock-Gallup road, 9 miles east of Tohachi.	Contact of alluvium and bedrock			2 springs.
31		1 mile southwest of Bennetts Peak				
32		1½ miles northwest of Bennetts Peak				
33		Just west of Chaco River, 12 miles northeast of Fords Peak.				
34		Southwest base of Mitten Rock				
35		In canyon on south side of Redrock Valley, 7½ miles west of Redrock store.				
36		In Chezhindeza Valley, 4 miles east of base of Carrizo Mountain.				
37		West side of Red Wash, 7 miles south of west of Shiprock.				
38		2½ miles west of Shiprock				
39		10 miles south of Shiprock				
40		East side of Hogback Mountain, 10 miles south of Jewett.				
41	Nikehoshi Spring	3 miles north of Deza Peak	Tertiary sandstone	10	Excellent.	Developed for irrigation; perennial.
42	Dadasoa	do	do	4	do	Do.
43	Greasewood Spring	4½ miles northwest of Matthews Peak	Chinle formation	.50		Slightly alkaline.
44	Toadlena	One-half mile west of Toadlena School	Alluvium and talus	1	Excellent.	Supplies school; also saved in reservoir; used for irrigation.
45		7 miles south of west of Tohachi	Contact of alluvium and sandstone of Mesaverde formation.	.08	Fair	
46		Base of mountain 3 miles southeast of Chuska Peak.	Shales of Mesaverde formation	1	Slightly alkaline.	
47		Base of mountain 2½ miles southwest of Chuska Peak.	Contact of alluvium and bedrock	.05–4	Good	A group of springs giving rise to a short brook.
48		South base of Defiance Mesas	Contact of Cretaceous shale and Tertiary sandstone.	3	Excellent.	2 springs in this locality give rise to a brook; perennial.
49		Todilto Park, one-half mile north of Beelzebub.	Wingate sandstone	.05	do	
50		2 miles southeast of Tsehili	Alluvium	.03–1		4 springs.
51		Along Spruce Brook	Bedding plane between sandstone of different texture and between talus and alluvium and rock; also from Tertiary sandstone.	.1–4	Excellent.	Several springs supplying perennial Spruce Brook.
52		Head of Lukachukai Creek	Alluvium over Tertiary sandstone	16		Springs along brook for miles.
53		11 miles south of Redrock store	Variegated shales of Chinle formation			
54		Arizona-New Mexico boundary line, 9 miles south of Redrock store.	Wingate sandstone			

NOTE.—Chuska Valley, 30–40; Chuska Mountains, 41–56.

55		2½ miles east of Hasbidito Spring	do.			
56		3 miles northwest of Chuska Peak				
57		Along edge of Chuska Mountain				Several springs at elevation of 8,200 feet.
58		East base of Chuska Mountain, north of Washington Pass.				3 springs at elevation of 6,000 feet, reported by Lieut. Brown.
59		Top of Beautiful Mountain				Several springs.
60		Middle northwest side of Beautiful Mountain				
61		Northeast base of Roof Butte				
62		In canyon 5 miles north of View Point				
63	Rock Springs	Sampson's store	Contact of shale and sandstone of Mesaverde formation.	2		Developed artificially by tunneling.
64		East side of Black Creek Valley, 5 miles southeast of Fort Defiance.	Contact of alluvium and sandstone.		Fair	
65		In canyon 4½ miles northwest of Manuelito railroad station.				
66	Tunnel Spring	3 miles northeast of Fort Defiance	Wingate sandstone		Good	In natural tunnel in Wingate sandstone.
67	Buell Park Spring	Buell Park	Bubbling spring in alluvium	1	do.	Issues from an area of swamp.
68	Hunter Point	Black Creek near Hunter Point	Contact of alluvium and shale	2	do.	Fluctuates greatly in volume.
69		On road at Red Lake (north of Fort Defiance)		.3		Tastes strongly of lime.
70	Tanner Spring	Lower Wide Ruin Wash	Sand dunes over Chinle formation	10	Good	Used for irrigation; perennial.
71	Oak Spring	Black Creek Valley	Contact of alluvium and bedrock; also from bedding planes in Moenkopi formation.		do.	
72	St. Michaels	St. Michaels	Contact of alluvium and bedrock	.5–2	do.	Several springs distributed along shallow arroyos; perennial.
73	Todokozh	5 miles southwest of Cross Canyon	Alluvium and eolian deposits	.07	Fair	Perennial.
74	Lizard Spring	6 miles north of Ganado	Contact of shale and limestone of Chinle formation.	1	Alkaline	
75	Segetoa Spring	Between Ganado and Fluted Rock	Contact of alluvium and sandstone	1	Good	
76	Sonsela Springs	Sonsela Buttes	Contact of lava and Chinle formation	.5–2	do.	6 or 8 springs emerge from beneath the lava; perennial.
77		West side of Black Creek Valley, 4 miles southwest of Hunter Point.	Alluvium concealing joints and bedding planes in rock.		do.	
78		3 miles southeast of Cornfields School	Landslide débris from Chinle formation.	1	Alkaline	
79		Bonito Canyon	Alluvial gravels and joints in Moenkopi formation.		Good	Supplies Fort Defiance.
80		Quartzite Canyon	Alluvium overlying rock; in joints in quartzite and in sandstone of the Moenkopi formation.		do.	A large number of springs and seeps forming a brook.
81		Fluted Rock	Contact of alluvium and bedrock	.5–1	do.	3 springs, 1 north, 1 east, and 1 south of Butte.
82		3 miles west of Fort Defiance sawmill	Contact of alluvium and sandstone	.7	do.	
83		On Ganado trail, 9 miles west of Fluted Rock	Contact of alluvium and sandstone; also from joints in sandstone.	.3–1	do.	Several springs in adjoining arroyos supply short stream.
84		On Chinle-Fort Defiance road, between sawmill and Chinle.	Alluvium over sandstone	2	Fair	Several seeps and small springs at head of drainage; perennial.
85		Upper Canyon de Chelly	Contact of Shinarump conglomerate and De Chelly sandstone.	.10–3	Excellent	Springs are distributed along the canyon at this horizon.
86		2 miles west of Tanner spring		.8		

NOTE.—Chuska Mountains, 57–62; Manuelito Plateau, 63–65; Black Creek Valley, 66–69; Defiance Plateau, 70–88.

Records of springs in the Navajo and Hopi reservations—Continued.

No.	Name.	Location.	Source.	Estimated flow (gallons per minute).	Quality.	Remarks.
87		1½ miles west of Wide Ruin store		0.7		
88		Old sawmill west of Fort Defiance		1		
89		On Ganado trail, 5½ miles west of Fluted Rock				2 springs.
90		Head of Nazlini Creek		3		Do.
91		Head of Monument Canyon				
92		On Chinle and Fort Defiance road, 14 miles southeast of Chinle School.	Contact of alluvium and bedrock	.1-.3		Several springs at head of shallow canyon.
93		2 miles northeast of Round Rock (Tsenakani)		.6		
94	Greasewood Spring	16 miles southwest of Sunrise Springs	Seep from dunes	.05	Excellent	Water held in artificial excavation in rock.
95	Sunrise Springs	11 miles southwest of Ganado	Tertiary sandstone and McElmo (?) formation.	.50	do	Developed by trenching; perennial.
96	Todokozh Spring	4 miles southwest of Mesa Ventana	Decomposed sandstone of McElmo formation.		Somewhat alkaline.	
97	Maito Spring	12 miles northwest of Chinle School	Alluvium and cross-bedding planes in Navajo sandstone.	3	Good	
98	Alamo Spring	15 miles northwest of Chinle School	do	4	do	
99	Hasbidito Spring	Three-fourths mile north of Los Gigantes Buttes.	Shales of Chinle formation	2	Alkaline	
100	Trout Spring	2 miles southeast of Lohali				
101	Shato Spring	1½ miles northeast of Trout Spring				
102	Sand Cone Springs	Chinle Valley, 11 miles north of Chinle School				
103	Setsiltso	West side of Chinle Valley, 16 miles northwest of Round Rock store.	Sandstone of La Plata group			3 springs; reported by Lieut. Gurovits, 1892.
104		Head of Beautiful Valley	Alluvium over rock	.60	Poor	
105		Chinle Valley, 7 miles northwest of Chinle School.				Lieut. Suplee reports no water (1893).
106		West side of Chinle Wash	Alcoves in Navajo sandstone	(*a*)	Excellent	Many such places; off trail; enough water for camp, but not for stock.
107		5 miles southeast of Bitsihuitsos Butte	Junction of cross-bedding laminæ in sandstone.	.05	do	
108		2 miles west of Bitsihuitsos Butte	Red shales of McElmo formation	1	Strongly alkaline.	
109		Cliff house in lower Chinle Wash	Joints in bedding planes in Navajo sandstone.	10	Excellent	
110		6 miles southeast of Chalstla	Joints in sandstone of La Plata group	.05	do	Reduced to a seep in dry seasons.
111		East side of Sahotsoidbeazhe Canyon, 10 miles southwest of Mexican Water.	Cross-bedding laminæ in sandstones of La Plata group.	2	do	Group of several springs.

NOTE.—Defiance Plateau, 89-93; Chinle and Pueblo Colorado Valleys, 94-114.

112	....	3½ miles west of Mexican Water	Navajo sandstone, joints, and bedding planes.	2	....	
113	....	3¼ miles south of Bitsihuitsos Butte	....	....	....	
114	....	1½ miles northwest of Bitsihuitsos Butte	....	....	....	
115	....	6 miles northwest of Bitsihuitsos Butte	....	....	....	
116	....	11 miles northwest of Bitsihuitsos Butte	....	....	....	
117	....	In canyon 11 miles northwest of Round Rock store.	....	....	....	
118	....	In canyon 11 miles northwest of Round Rock (next west of 117).	....	....	....	
119	....	West side of Chinle Valley, 19½ miles northwest of Round Rock store.	....	....	....	
120	....	East side of Chinle Valley, 18 miles northwest of Round Rock store.	....	....	....	
121	French Spring	2 miles east of French Butte	Contact of lava and sedimentary rock	1	Fair	
122	Mal Pais Spring	4 miles west of Twin Buttes	Contact of lava and sandstones	40	do	
123	Tohasged	Near Maddox	Talus of lava	.50	do	
124	Notatasaca	Tusayan quadrangle	On shale between lava and tuff	1	Excellent.	
125	Big Spring	Near Maddox	do	1.3	Good	
126	Mason Spring	2 miles north of Pyramid Butte	Contact of alluvium and shale	2	do	Undeveloped; capable of yielding 6 to 7 gallons.
127	Myrick Corral	Chandler ranch	do	1.5	do	Spring developed from seep; perennial.
128	Coyote Spring	South of Pyramid Butte	do	4	do	Perennial.
129	Lokasakad Spring	3 miles west of Indian Wells	Probably from contact of lava and sedimentary rock; bubbling spring from mud.	15	do	Perennial. (See p. 112.)
130	Bidahochi Spring	Base of Bidahochi Butte	Contact of lava and shales	....	....	
131	Lava Spring	4 miles northeast of Indian Wells	do	.50	Good	
132	Cedar Springs	One-half mile southeast of Comar Spring	Talus covering contact of lava and shale; joints in lava.	.80	do	Developed by trenching; perennial.
133	Comar Spring	On Winslow-Keams Canyon road, 3½ miles south of Egloffstein Butte.	Contact of rock and coarse sands	12	Slightly alkaline.	Perennial.
134	Cottonwood Spring	8 miles north of Indian Wells	Contact of ash and shale	.30	Sweet and cool.	Do.
135	White Cone Spring	1½ mile northeast of White Cone	do	1	Good	Do.
136	Smith Spring	North base of Smith Butte	....	....	....	
137	....	Hopi Buttes country	Contact of lava and tuff with shales and sandstone.	....	Good	Many seeps and small springs at base of lava-capped buttes and mesa; could be developed.
138	....	1½ miles north of Cottonwood Spring	Contact of ash and shale	.10	Fair	
139	....	6½ miles northwest of Smith Butte	....	....	....	
140	....	7 miles west of north of Smith Butte	....	....	....	
141	....	8 miles north of Smith Butte	....	....	....	
142	....	3 miles southeast of French Spring	....	....	....	
143	....	1½ mile east of French Spring	....	....	....	
144	....	2½ miles east of French Spring	....	....	....	
145	....	3 miles east of Maddox	....	....	....	

a Slight flow.

NOTE.—Chinle and Pueblo Colorado Valleys, 115–120; Hopi Buttes, 121–149.

Records of springs in the Navajo and Hopi reservations—Continued.

No.	Name.	Location.	Source.	Estimated flow (gallons per minute).	Quality.	Remarks.
146		2 miles northeast of Maddox				
147		$3\frac{1}{2}$ miles south of west Maddox				
148		South side of mesa 4 miles southeast of Twin Buttes.				
149		5 miles southwest of Lokasakad Spring				
150		6 miles southwest of Lokasakad Spring				
151		$3\frac{1}{2}$ miles southwest of Cedar Spring (Hopi Buttes)				
152		4 miles south of Cedar Springs (Hopi Buttes)				
153		$2\frac{1}{2}$ miles south of Cedar Springs (Hopi Buttes)				
154		1 mile south of east of Cedar Springs (Hopi Buttes).				
155		1 mile north of Cedar Springs (Hopi Buttes)				
156		3 miles north of Cedar Springs (Hopi Buttes)				
157		$3\frac{1}{2}$ miles northeast of Cedar Springs (Hopi Buttes).				
158		5 miles northeast of Comar Springs				
159		9 miles northwest of Indian Wells				
160	Burro Spring	Oraibi Wash, 13 miles west of south of Oraibi	Contact between rock strata	0.50	Good	Little Burro Spring near at hand has about same flow; perennial.
161	Coyote Spring	5 miles south of Giant's Chair				
162	Honani Spring	4 miles west of Burro Spring				
163	Dinnebito Spring	5 miles southwest of Padilla Mesa, sec. 20, T. 27 N., R. 13 E.				
164	Muencovi Spring	$2\frac{1}{2}$ miles south of Dinnebito Spring				
165	Tishepi Spring	5 miles south of Dinnebito Spring				
166		$3\frac{1}{2}$ miles southwest of Burro Spring	Contact between rock strata	.40	Excellent	
167		$8\frac{1}{2}$ miles south of Dinnebito Spring				
168		4 miles southwest of Giant's Chair				
169		4 miles south of White Cave Spring				
170	Tuye Spring	In cave near Steamboat Canyon	Contact of Dakota and McElmo formations.	.50	Excellent	Water stored in cave tank; perennial.
171	Senatoa Spring	2 miles north of Tuye	do	1	do	Perennial.
172	Jadito Springs	6 miles east of south of Keams Canyon	Alluvial deposits	7	Fair	A group of springs; perennial.
173	Marty's	5 miles north of Jadito store	Contact of Mesaverde and Mancos (?) formations.	1	do	Perennial.
174	Awatobi Spring	Just south of Talahogan Spring	Contact of alluvium and sandstone	2	do	One of the Talahogan group; used by cliff dwellers; perennial.
175	Talahogan Springs	Head of eastward-trending canyon, 6 miles southwest of Keams Canyon and 5 miles northwest of Jadito Spring.	Contact of alluvium and shale; water concentrated by joints.	2	do	This group of springs after development should yield 15 to 20 gallons per minute; perennial.

NOTE.—Hopi Buttes, 150–159; Tusayan Washes, 160–169; Black Mesa, 170–177.

176	Chief Spring	2 miles north of Talahogan Spring, in sec. 2, T. 27 N., R. 19 E.	Contact of alluvium and sandstone	1.5	do	
177		Keams Canyon	Contact of shale and sandstone of Mesaverde formation.	20		5 springs connected with one pipe to supply school. Many other undeveloped springs at same horizon.
178	First Mesa Spring	Base of First Mesa, in sec. 14, T. 28 N., R. 18 E.	Landslide débris; water from contact of Mancos and Mesaverde formations.	1		
179	Walpi Spring	Base of First Mesa, in sec. 15, T. 28 N., R. 18 E.	Landslide débris	.80		
180	Tewa Spring	Base of First Mesa, near Hano, in sec. 11, T. 28 N., R. 18 E.	Landslide débris, concealing horizon at base of Mesaverde formation.	1		
181	Shongopovi Spring	At school	Contact of Mesaverde and Mancos formations concealed by landslide materials.	1	Fair	A spring used for centuries and until recently polluted.
182	Wepo Springs	Wepo Wash, in sec. 25, T. 29 N., R. 18 E.	Contact of sandstone and shale in Mesaverde formation.	30	Good	Includes 3 springs, one-half mile north of sheep dip; 1 big spring 1 mile south of sheep dip; 1 spring fills 5,000-gallon tank in 7 hours; perennial.
183	Onion Springs	In Oraibi Wash, 11 miles north of Oraibi, in sec. 22, T. 30 N., R. 17 E.	Contact of beds in Mesaverde formation.	2	do	
184	Hotevila Spring	4½ miles northwest of Oraibi		1		
185	Kydestea Spring	Black Mesa, in canyon tributary to Moenkopi Canyon.	Strata in Mesaverde formation	3	Fair	Perennial.
186	Chilchinbito Spring	Northeast base of Black Mesa	Sands in wash and shales	.20-1	Alkaline	Several springs along the valley at this point yield small quantities; perennial.
187		Base of First Mesa, in sec. 30, T. 29 N., R. 18 E.				
188	Canella Spring	West side of First Mesa, 2¼ miles north of Hano, in sec. 25, T. 29 N., R. 18 E.				
189	Antelope Spring	5 miles north of Hano, in sec. 14, T. 29 N., R. 18 E.				
190	Goat Spring	9 miles north of Shipolovi, in sec. 2, T. 29 N., R. 17 E.				
191	Solomy Spring	2½ miles southwest of Hotevila, in sec. 26, T. 29 N., R. 15 E.				
192	White Cave Spring	9½ miles southeast of Blue Canyon				
193	Togoholtsoe Spring	3½ miles south of Zillesa Mesa				
194	Nottahndelit Spring	27 miles south of Chilchinbito				
195	Lokasakal Spring	27 miles south of Chilchinbito				
196	Tohadistoa Spring	23 miles south of Chilchinbito				
197	Teadepahto Spring	18½ miles south of Chilchinbito store				
198	Salt Spring	Black Mesa, 10 miles southwest of Tyende				
199		7 miles west of Eagle Crag	Contact of strata in Cretaceous sandstone.			
200		In Jadito Wash, 2 miles above Marty's	Contact of Mesaverde formation and Mancos shale.	2	Good	Group of springs.
201		Head of East Fork of Jadito Creek	Contact of shale and sandstone in Mesaverde or Mancos.	.50		
202		Base of Salahkai Mesa	Contact of Mesaverde formation and Mancos shale.	.5-2	Fair	3 springs in addition to a number of seeps.

NOTE.—Black Mesa, 178-206.

Records of springs in the Navajo and Hopi reservations—Continued.

No.	Name.	Location.	Source.	Estimated flow (gallons per minute).	Quality.	Remarks.
203		2 miles southwest of Lohali	Alluvium over rock	0.03	Fair	
204		4½ miles north of Lohali	Contact of Mancos and McElmo formations.	.05	Alkaline	
205		7½ miles north of Lohali	do	1	do	
206		2 miles northeast of Oraibi Butte	Mancos shale	.30	Fair	Group of several springs and seeps; perennial.
207		In Moenkopi Canyon, 6½ miles northwest of Ziltahjini Peak.	Contact between shale and sandstone of Mesaverde formation.	.1-6	Fair; some alkali.	Many springs issue from the walls of Moenkopi Canyon and its tributaries.
208		1¾ miles north of Chilchinbito Spring	Crevices in sandstone of McElmo formation.	.10	Excellent	The only spring free from alkali noted within a wide area.
209		Tyende-Chilchinbito trail; two springs 1 mile off of trail, one on trail.	McElmo-Dakota contact	.2-2	Alkaline	A weak spring, 2 miles north of Chilchinbito, issuing from sandstone; contains good water.
210		Black Mesa, 7 miles south of Tyende	Contact of alluvium and sandstone	1	Good	Stored in pools for stock.
211		Base of mesa, 6 miles northeast of Tuye Spring				2 springs.
212		Head of West Fork of Jadito Creek				
213		9 miles northeast of Keams Canyon School				
214		9 miles north of Keams Canyon School				
215		West side First Mesa Wash, 3½ miles northeast of Wepo Spring.				
216		Second Mesa Wash, 5½ miles northeast of Shipolovi.				
217		Northwest of store at Oraibi				
218		Oraibi; at base of cliff under sandstone				
219		2½ miles west of south of Onion Spring				
220		3 miles southeast of Zillesa Mesa				
221		14 miles northeast of Keams Canyon School				
222		2½ miles northwest of Teadepahto Spring				
223		In south canyon tributary to Moenkopi Canyon, 2 miles east of Blue Canyon.				
224		Moenkopi Canyon, three-fourths mile below Blue Canyon.				
225		Northwest base of Black Mesa, south of lake				2 springs, 2 miles apart.
226		West base of Howell Mesa	Contact of Mesaverde formation and Mancos shale.	.80	Good	
227		5 miles west of Howell Mesa	Contact of sandstone and conglomerate	1	do	Perennial.
228		In canyon tributary to Moenkopi, 8 miles west of Blue Canyon.				

NOTE.—Black Mesa, 207-225; Moenkopi Plateau, 226-228; Kaibito Plateau, 229-234.

229	Tuba Springs	Tuba				See pp. 143–146, Pl. XXVII, and fig. 16.
230	Springs in Reservoir Canyon.	Reservoir Canyon near Tuba				
231	Moa Ave Springs	Moa Ave				
232	Willow Springs	Base of Echo Cliffs				
233	Kaibito Springs	22 miles north of Wildcat Peak	Contact of alluvium and bedrock	4	Fair	Group of several springs giving rise to stream; perennial.
234	Whitmore Pools	Southwest of Preston Mesa				
235	Dove Spring	6 miles south of Keams copper district				
236		5½ miles east of north of Wildcat Peak				
237		Canyon at west base of White Mesa				
238		Canyon on White Mesa				
239		Side canyon tributary to above				
240	Sethlekai	Southwest base of Navajo Mountain	Probably at contact of Todilto formation with Navajo sandstone.	3	Excellent	Used for irrigation by cliff dwellers; perennial.
241	Fault Spring	In Junction Canyon one-half mile from San Juan River.	Crack along fault of small displacement in Navajo sandstone.	1	...do	Perennial.
242		10½ miles east of north of Inscription House National Monument.	Contact of alluvium and sandstone	2	Good	
243		12 miles north of Inscription House National Monument.	Cave in Navajo sandstone	.50	Excellent	
244		Desha Canyon	Probably at contact of Todilto formation with Navajo sandstone.	10	...do	Used for irrigation by cliff dwellers; perennial.
245		Canyons north of Navajo Mountain	Between Todilto formation and Navajo sandstone and between beds of Todilto formation.			Evaporation so great that flow is nearly all absorbed.
246	War God Spring	Southeast side of Navajo Mountain; elevation 8,600 feet.	Talus and "rock flow" cover	25	Excellent	Gives rise to a brook; temperature, 47°; perennial.
247	Endischee	Southwest flank of Navajo Mountain	From talus	3		
248	Shato Spring	Middle Shato Valley	Contact of Navajo sandstone and Todilto formation.	3	Excellent	Several other seeps near at hand.
249		Mouth of Shato Canyon				
250	Chief Spring	9 miles west of Tyende	Alluvium over sandstone	1.5	Good	
251	Boiling Spring	Segi Canyon	Boiling spring in alluvium	2	Excellent	Perennial.
252	Segihatsosi Spring	Segihatsosi Canyon	Alluvium	.3–2	Good	10 or 15 springs, many of them perennial.
253	Upper Crossing	Piute Canyon, head of box canyon on trail	Contact of Chinle and Wingate formation.	4	Excellent	Gives rise to a brook; perennial.
254	Lower Crossing	Piute Canyon, 5 miles from mouth	Contact of Wingate and Chinle formations.	30–40	...do	Used for irrigation; perennial.
255		Laguna Canyon, 2 miles below Boiling Spring	Contact of alluvium and bedrock	3	Good	
256	Keet Seel	In canyon, 1 mile above Keet Seel National Monument.		6	...do	
257		Head westernmost canyon on Tyende Mesa				
258		7 miles north of Agathla				
259	Cedar Spring	Monument Valley (Utah)	Contact of sandstone and red shales	.20	Fair	
260		4 miles east of Agathla	Contact of Shinarump conglomerate and Moenkopi formation.	(a)	Excellent	

a Slight.

NOTE.—Kaibito Plateau, 235–239; Rainbow Plateau, 240–245; Navajo Mountain, 246–247; Shato Plateau, 248–249; Segi Mesas, 250–258; Monument Valley, 259–262; Gothic Mesas, 263.

Records of springs in the Navajo and Hopi reservations—Continued.

No.	Name.	Location.	Source.	Estimated flow (gallons per minute).	Quality.	Remarks.
261		West and southwest of monuments	Shinarump conglomerate and Moenkopi formation.	0.05–1	Excellent	Several springs and seeps issue from rock in this region.
262		North side Gypsum Valley north of east of Agathla.				
263	Hohwasshahan (Lieut. Gurovits).	Head of canyon 5 miles south of Hogansaani Spring.				Lieut. Gurovits noted 5 springs here in 1893.
264	Hogansaani Spring	Tisnasbas-Tyende road, 25 miles southwest of Tisnasbas store.	Bedding plane of Wingate sandstone	.50	Excellent	Several seeps in this locality.
265	Todokozh Spring	16 miles southwest of Bluff on road to Mexican Water.				Reported by Lieut. Gurovits.
266	Tohanadla Springs	12 miles southwest of Bluff on road to Mexican Water.		[a] 182		2 springs reported in 1893 by Lieut. Gurovits.
267		6 miles northeast of Hogansaani				
268		Southwest of Carrizo Mountain on the Seklagaidesa-Redrock trail.	Bedding planes in Chinle formation		Alkaline	Perennial.
269		Cornfields, Tochinlini	Contact between laminæ in Wingate sandstone.	.50	Good	Do.
270		2 miles southwest of base of Chezhindeza Mesa	Wingate sandstone	.75	Excellent	Do.
271		Southwest base of Chezhindeza Mesa	Alluvial deposits near base of mesa	.75	Good	Do.
272		North base of Carrizo Mountain west of Tisnasbas	McElmo formation			Several small springs.
273		Southeast base of Carrizo Mountain	Bedding planes of Wingate sandstone	.25–.50		Several springs of this type.
274		End of ridge 4 miles east of Pastora Peak	Contact of talus and white sandstone	.25	Excellent	Perennial.
275		1½ miles southwest of Pastora Peak; head of Chonati Canyon.	Contact of alluvium and rock		do	Do.
276		2 miles northwest of Pastora Peak	Contact of alluvium and white sandstone.	.50	do	Springs of this type on summit of Carrizo Mountain; perennial.
277	Tucker Spring	5 miles north of Winslow	Shinarump conglomerate	([b])	do	Water held in artificial tunnel; perennial.
278	Box Springs	4 miles below Grand Falls	Bedding planes and joints, Moenkopi formation.	10	Slightly alkaline.	A group of 5 springs; perennial.
279	A1 Ranch Spring	Little Colorado, 5 miles above Tanner Crossing	do			
280	Warner Wash	4 miles above Tanner Crossing	do	12	Fresh; good	Group of springs emerging from rock floor of wash; perennial.
281	Janus Spring	1 mile above Government bridge	Vertical joints in Shinarump at or above Moenkopi contact.	1	Excellent	Cement tank; perennial.
282	Navajo Springs	4½ miles south of Lee Ferry		2	do	
283	Bitter Spring	do	Landslide material	6	Intensely alkaline.	Group of several springs.

[a] 1893. [b] Flows part of year.

NOTE.—Gothic Mesas, 264–267; Carrizo Mountain, 268–276; Painted Desert, 277–283.

WELLS.

GENERAL CONDITIONS.

It is conceivable that the development of all the springs and the construction of hundreds of storm-water reservoirs might bring the grazing lands of the Navajo country within the reasonable reach of water for stock. The cost of such work, however, is large and the supplies obtained vary widely in response to fluctuating rainfall, evaporation, and wastage through porous soils; attention has therefore been directed to wells as a means of supplementing the present meager supplies. Wells have the distinct advantage of furnishing water at the point where needed; they permit the selection of sites for corrals, Indian homes, hospitals, schools, and farms, on the basis of quality of soil, nature of the grazing lands, supply of timber and fuel, or other factors besides nearness to water. At present white settlements are placed on a watercourse or at a spring and the Indian makes his home in similar localities. When forced to move by shortage of water or scarcity of forage, the Navajo relocates at another spring, thus passing his nomadic life in shifting from water hole to water hole. The result is that parts of the reservation are badly overgrazed and that food for sheep and horses is absent from the vicinity of springs and perennial watercourses. Some of the best grass lands on the reservation are little used, and the Indian is restricted in development by overcrowding in sections where water is ample. If the lands of the reservations are to be allotted to individuals and families of the Hopi and Navajo tribes many small supplies of water must be provided, preferably one for each few sections of land; supplies sufficient not only for several hundred sheep but also to irrigate a small garden. I see no way by which this stage of combined stock raising and agriculture can be attained by the Navajos without the digging of wells. Wells of large flow will probably always be the exception in this region and they are not essential to its development. Sheep consume 1½ gallons of water a day and horses about 10 gallons a day; a well, therefore, yielding 2 gallons a minute will serve for 10 horses and 1,000 head of sheep and for the irrigation of a small tract, and still provide water for domestic use.

In a few parts of the area the quality of well water is likely to be unsatisfactory, but as a rule the beds best adapted to yield water to wells are least liable to carry salts which render water unpalatable for man or beast. It should be borne in mind that we are dealing with arid conditions; that a well yielding 5 gallons of water a minute is an "excellent well"; that reliability rather than quantity is of fundamental importance; that the temperature of the water is a minor matter; that the presence of iron, sulphur, salt, alkali, unless in quantities dangerous to health, may be disregarded. All liquids

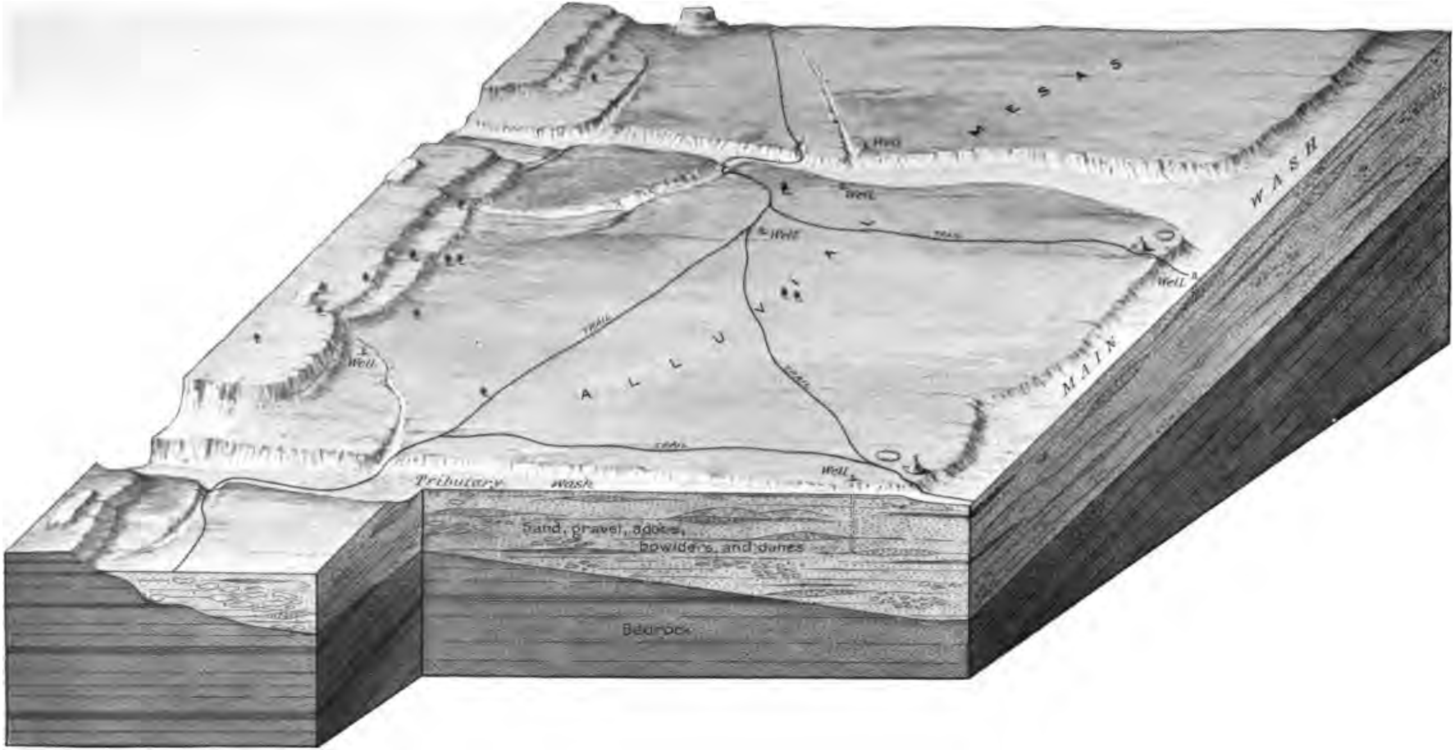
flowing as streams, or from springs, or held in pools, or pumped from wells, are water in a desert country; and a man who applies the criteria of taste, odor, and appearance might die of thirst on the Navajo Reservation.

WELLS IN UNCONSOLIDATED SEDIMENTS.

CHARACTER OF THE SEDIMENTS.

Materials which have been deposited by streams, by wind, and by lakes, and which have not yet become converted into solid rock, may be grouped as "unconsolidated sediments" in contrast to sandstones, shales, and limestones, in which the constituent materials are compacted and held together by cement to form "bedrock" or "ledge." The composition and arrangement of layers of sand, gravel, clay, silt, and adobe, which make up the unconsolidated sediments may be examined on the floors of dry canyons, the banks of arroyos, the beds of ephemeral lakes, the flood plains of the washes, and in the sand dunes of wind-swept flats. Materials of this character partly fill the valleys and washes of the Navajo country to various depths. In the Little Colorado Valley the wells at Leupp show a depth to rock of over 60 feet; for the Oraibi Wash the figures are 60 to 80 feet; in the Puerco Valley a filling of 50 to 70 feet has been found at several places; and a well at Gallup penetrates 175 feet of alluvial deposits before reaching bedrock.

These unconsolidated sediments are capable of holding large amounts of water, which in many places may be recovered by wells. It should be borne in mind that not all parts of the great mass of unconsolidated materials can yield water, and that two wells within a few hundred feet of each other may give widely different results. These conditions may be understood when the process by which the sediments are deposited is examined: Streams flowing from the highlands toward a valley carry materials weathered from rocks. In the upper, swifter stretches of a stream materials of all sizes are hurried along, but when the stream emerges from its canyon and enters flatter lands the coarser part of its load is deposited first and the finer parts are carried farther out into the valley. Bowlders, or gravel and bowlders, or bowlders, gravel, and sand, therefore predominate on the upper valley slopes, and sands and silts and adobe may cover the valley floor. If the streams feeding the valleys and washes were of uniform volume throughout the year a zone of coarse materials on the upper slopes and at heads of valleys would be followed downward by zones of increasingly finer materials, and the central section of the washes would be floored by layers of clay and silt and the finest sands. However, the streams of the reservation fluctuate widely in volume; floods capable of carrying large



STEREOGRAM ILLUSTRATING THE CHARACTER AND DISTRIBUTION OF MATERIALS FILLING THE LARGER WASHES OF THE NAVAJO COUNTRY AND FAVORABLE LOCATIONS FOR WELLS.

bowlders miles beyond a canyon mouth follow stages during which streams are able to transport fine sand only. The result is that over the entire floor of the wash fine sediments may be overlain by coarse gravels or beds of bowlders, and gravels may be buried by sands of various degrees of fineness. Moreover, the streams on alluvial slopes shift their position from time to time, even during the course of a single shower, and deposit their loads in a capricious manner. A vertical section through such deposits, as, for example, a well, shows therefore fine and coarse materials at various levels, and the order in which sands and gravels occur may differ widely in two adjoining wells. A water-bearing horizon found in a drill hole at a depth of 30 feet may be at a higher or lower level or be entirely absent in a well 1,000 feet distant. The irregularity of deposition is further increased by a redistribution of the fine sands under the action of the wind and by the deposition of finest silts and adobe on the floor of ephemeral lakes which dot the wide, flat-floored washes during the rainy season. (See Pl. XXVIII and fig. 18, p. 164.)

The bedrock underlying unconsolidated deposits is in most places less pervious than the deposits themselves. These rocks therefore serve to hold the ground water at a more or less definite horizon and to prevent its escape downward. Local depressions in the rock floor are of particular value in this respect. Certain parts of the larger washes, as the Puerco between Manuelito and Gallup and the Pueblo Colorado between Sunrise Springs and Twin Mesas, appear to be rock basins filled with sands and gravels, which in turn are saturated with water. Though many such depressions probably occur beneath the alluvium of the washes and to a greater or less extent in many canyons, their precise position can be determined only by systematic exploration with drills.

LOCATION OF WELLS.

WELLS ALONG THE AXES OF THE WASHES.

Within the immediate flood plain of ephemeral streams or washes water is usually to be found at depths within 10 feet, and many shallow wells were noted, especially in localities where rock lies but a short distance below the bed of the dry stream courses. Some of these wells are protected by rock or brush and last for several years; most of them are alternately destroyed and renewed with the passage of flood waters. At Bardgeman Wells, in Coyote Wash, water is obtained from two holes, each about 6 feet deep, sunk in the bed of the wash, and from a well on the immediate bank in which water stands 14 feet below the surface and 5 feet above bedrock. At Greasewood Springs (Navajo, Dowuzhibito), where the flood chan-

nel of the Pueblo Colorado Wash attains a width of about a mile, there are several wells constructed by the Indians under the direction of officials—wells that recover good water at depths of 4 to 8 feet. In the course of our work a number of such shallow dug wells were used and many were constructed during the dry months of May, June, and parts of July.

WELLS ON ALLUVIAL MESAS OR BENCH LANDS.

Adjoining the main channels of the larger washes the surface of alluvial fill rises by steps or as a gradual slope and forms wide expanses of sand and gravels, in many places trenched by arroyos and coated with drifting sand. Parts of these extensive flats may be flooded in exceptional years, but under normal conditions they remain dry land, and where soil is suitable offer opportunities for irrigation. It is on these benches and lower valley slopes that wells in unconsolidated sediments can be most favorably located.

At Holbrook the underflow of the Puerco and Little Colorado is recovered by wells sunk in the alluvial benches on which the village is situated. Water is struck at 10 to 20 feet below the surface, but well points are driven to depths of 20 to 35 feet, some of them 60 to 100 feet, with the hope of obtaining the "second" or "third" water, which is usually of better quality. The water used by the Santa Fe Railway at Holbrook is obtained from a stone-lined well 65 feet deep and 30 feet in diameter, in which the water stands 14 feet below the surface. The well is pumped from 2 to 4 hours a day, and during the week ending June 27, 1909, the time of my visit, was supplying water at the rate of 52,800 gallons a day. The irregularity in distribution and in dimensions of the layers of sand, gravel, and silt constituting the alluvial fill of the Puerco and Little Colorado Valley is shown by the difference in material encountered in wells on adjoining lots, and by wide variations in salinity of waters from neighboring wells and also from various depths.

At St. Joseph wells sunk 40 to 60 feet into alluvium obtain water from gravel lenses at depths of 16 feet and below. The supply for domestic use, for stock, and for irrigation at the Indian school at Leupp is also obtained from wells which penetrate the alluvium of the Little Colorado Valley. The original battery of 10 driven wells reaching depths of 20 to 30 feet recovered about 80 gallons per minute. Five additional wells sunk in 1909 struck water at depths of 10 to 20 feet, and three of them which were continued downward to bedrock with depths of 77, 80, and 90 feet, respectively, found water in each stratum of sand and gravel penetrated. A test of one of the wells showed a yield of 162 gallons a minute. Nine miles below Leupp, at Tolchico, on the upper flood plain of the Little Colorado, wells 14 feet deep recover large supplies of water.

In the Leroux and Cottonwood washes ample supplies for cattle ranches are obtained from the alluvial fill at depths usually less than 30 feet. At the Wallace, Donahue, and Hennessy ranch, near Adamana, driven wells are used, and I am informed by Mr. Hennessy that the "first water," struck at about 17 feet, is in general alkaline; that at 30 feet it is slightly salty, but at depths between 40 and 50 feet pure water is obtained. In this area "salt wells," "alkali," and "fresh" wells occur at distances less than one-half mile apart.

A well at the Tohachi Mission, sunk 45 feet into the gravels of the upper valley floor at the base of Chuska Mountain, contains 8 feet of water even during the dry season.

In Wide Ruin Wash the only unfailing supply of water between Tanner Spring and Wide Ruin is obtained from a well dug in an alluvial terrace. This well is curbed with timber and reaches a depth of 37 feet, including 5 feet of water. Three wells in similar locations, and yielding satisfactory supplies, have been dug at Ganado to depths 14 to 20 feet. Water is also obtained in the Oraibi Wash at depths between 5 and 30 feet, in the Black Creek Valley at depths usually less than 10 feet. At the Cornfields School, below Ganado, it was found necessary to pass through 56 feet of sands and gravels before a stratum was discovered which yielded sufficient water to supply the local needs.

Water from the highlands tributary to a wash is poured out over the long alluvial slopes and makes its way both on the surface and underground toward the axis of the main wash. Part of the amount remaining, after the run-off and evaporation have taken their toll, approaches the surface or actually emerges as springs or seeps on the flat central floor of the wash. Generally speaking, the depth to water increases as the alluvial slopes are ascended, for, as shown by Meinzer,[1] although the water table slopes upward in the direction of the mouths of contributory canyons, whence the principal supplies of water are derived, the surface of the ground also slopes upward, and usually at a more rapid rate. Water is, therefore, likely to be found at the least depth near the main channels of a wash, and it seems desirable to select well sites on the borders of the wash above the reach of the highest floods. Chances for success are improved by the selection of a site near the junction of a tributary wash with the main channel.

WELLS IN HIGH VALLEYS.

Unlike the deeply filled troughs of the large washes, many of the upper tributary valleys are thinly veneered with sediment, at the base of which, lying on bedrock, water may be found.

[1] Meinzer, O. E., U. S. Geol. Survey Water-Supply Paper 277, p. 36, 1911.

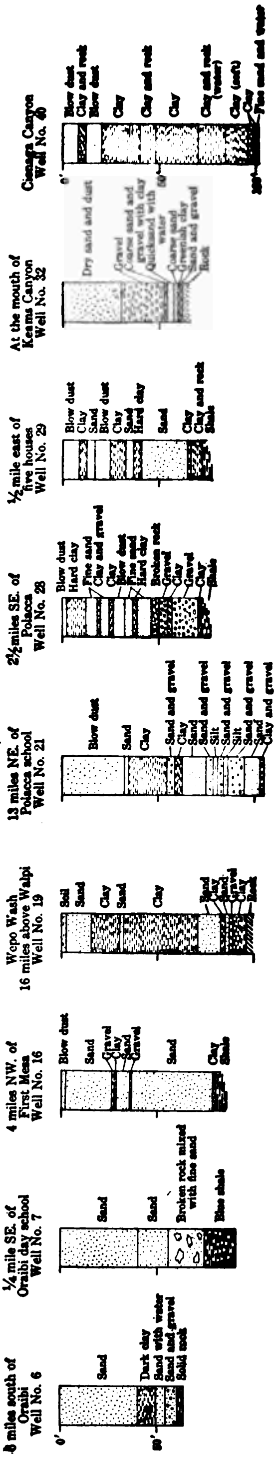


FIGURE 18.—Sections of wells in unconsolidated deposits, Tusayan Washes.

At Douglass Camp, in Monument Valley, two wells, 10 and 12 feet deep, have rock bottoms covered 2½ feet deep with water. The water used at Wide Ruin is obtained from a well 15 feet in depth in which the water stands throughout the year at about 6 feet below the surface. It is near the head of a narrow canyon, whose floor is covered with sand and gravels, partly cemented. This well was utilized some hundreds of years ago by the people who occupied the walled inclosure and fragmentary pueblos now known as Wide Ruin. No trace of a well was found when the white man first visited these ruins, but excavation revealed one 16 feet square, walled with flat slabs of stone and with a flight of stone steps leading to the water. The well at the Navajo sawmill is dug in the alluvial fill of a flat swale near the head of a rock-walled canyon. The water rests on the rock beneath the sands, at a depth of 14 feet. A well sunk in rock, near at hand, yields no water.

The position of all the wells mentioned was determined by the presence of seepage at points farther down the valley. Without the guidance of such seeps or of alkali flats, or at least moist ground, wells in high valleys can not be located with assurance of success.

WELLS IN THE TUSAYAN WASHES.

The Tusayan Washes include four large channels: Jadito, First Mesa (Polacca), Oraibi, and Dinnebito, in addition to numerous tributaries, all of which combine to carry the run-off from the larger part of Black Mesa. Their drainage areas are: Jadito, 623 square miles; First Mesa, 672 square miles; Oraibi, 652 square miles; Dinnebito, 812 square miles. The average rainfall over this area is probably less than that at Keams Canyon (10.94 inches), for,

although the precipitation on Black Mesa may be 12 or 13 inches a year, the lower portions of the washes probably receive less than 8 inches. By assuming a mean annual precipitation of 9.5 inches we find that the water which falls within the drainage basins of the Tusayan Washes amounts to about 1,400,000 acre-feet a year. The Oraibi Wash alone collects each year 330,000 acre-feet, and First Mesa Wash 340,000 acre-feet. These washes are filled to depths of 10 to 90 feet with adobe, silt, and fine sand, with smaller amounts of coarse sand and gravel. The average porosity of these materials is not far from 25 per cent. Moreover, though the gradient of the washes is about 25 feet to the mile, long stretches drop less than 10 feet in a mile, and other sections of their courses are so flat that lakes covering hundreds of acres are formed during flood seasons. It thus appears that opportunities for filling the ground-water reservoir are favorable. Springs are rare along these washes, and the conditions for construction of storage reservoirs are not good; it was therefore decided to explore this area for underground water. Oraibi and First Mesa washes were selected for study and drilling was begun in 1910. During the two following years 29 wells were sunk in localities chosen to give the largest amount of information regarding the conditions under which water occurs in alluvial fill. Logs of nine of these wells are given in figure 18.

Five wells were sunk in the lower Oraibi Wash on a low-grade fan deposited by ephemeral streams. The materials of the fan were known to be fine and very irregularly distributed, but it was hoped that lenses of gravel were included, and that a water horizon would be encountered between the unconsolidated cover and bedrock. Neither of these expectations was realized. The silt was found to be excessively fine, "blow dust" of the drillers, and though saturated dust and moist sand were encountered no water was fed into the well. It would appear that the silt and adobe distributed as lenses was able to prevent both horizontal and vertical percolation. In fact, some of the material is so fine that it might be safely used in the construction of earth dams. The upper 28 feet of a drill hole, sunk by hand during June, 1909, gave the following typical section:

Section of hand-drilled hole, lower Oraibi Wash.

	Thickness.	Depth.
	Feet.	*Feet.*
Wind-blown sand	2	2
Hard-packed adobe	6	8
Fine red clay rendered soft by water	1	9
Very fine, hard-packed sand	3	12
Coarse sand	1	13
Adobe, white, dry	5	18
Very fine sand, moist	4	22
Clay and very fine sand, moist	6	28

In all wells sunk moist sand was encountered between depths of 6 to 30 feet, below which point the materials encountered were generally dry and hard packed.

In the upper Oraibi Wash a well 6 miles south of Oraibi and one at the Day School recovered 500 gallons an hour each, the largest flow coming from the bottom sands overlying bedrock. Two shallow wells near the base of the mesa at Bacobi were abandoned because the supply was insufficient to justify the installation of windmills.

In the open floor of the First Mesa Wash five successful wells yield from 300 gallons an hour to "more than the pump could pull," obtained at depths exceeding 100 feet. Two other wells were abandoned at 46 feet and 60 feet, respectively, on account of quicksand.

Along the upper Wepo and upper First Mesa washes, where the alluvial fill consists of coarser material, the five test wells encountered rock at depths between 80 and 102 feet. The largest amount of water was discovered between 57 and 85 feet. Five wells were sunk at Five Houses, all of them reaching rock at depths between 52 and 84 feet. Four of these wells obtained water in quantities insufficient to encourage development; the fifth, less than a mile distant from the dry holes, discharged on a test run 350 gallons per hour. No better demonstration of the sporadic distribution of water-bearing beds need be desired.

In Cienega Canyon, a tributary of Keams Canyon, nine wells were driven a short distance apart. The records at hand for six of the wells show that the water from five could not be developed "on account of fine sand," and that the sixth well, 80 feet deep, obtains 400 gallons an hour of water from a bed of sand 60 feet below the surface.

The results of drilling in the Tusayan Washes, combined with the knowledge obtained from the wells sunk in Leroux and Cottonwood washes, justify the expense of exploratory work in all the larger washes on the reservations where water is desired. Failures are, however, to be expected, and the most serious problem confronting the driller is the proper treatment of quicksand. If suitable strainers can be devised the number of "dry" wells may be greatly reduced.

CONSTRUCTION OF WELLS.

THE PROBLEMS.

Among the problems confronting the well maker working in unconsolidated sediments of the Navajo country are the following:

1. Excessively fine sand, "blow dust" in the driller's parlance, may be expected in all holes. This dust caves readily and when moist flows with ease. Though often found in saturated condition, its waters are held tight by capillarity.

2. "Quicksand" is an almost universal accompaniment of sands and gravels in washes.

3. Water is contained in lenses of sand, gravel, and bowlders which are sporadically distributed both horizontally and in vertical section.

4. Alkali water, salt water, and fresh water occur in "streaks" at various levels and at unknown distances apart.

5. Except at school and agency sites, the well is to be used by the Navajo, Hopi, or Piute, people who know little about pulley wheels, who can not repair a pump or windmill, and to whom an engine is a mystery.

6. Fuel for operating drills is practically absent from the large washes; water is scarce and supplies must be obtained from distant points. Wells therefore are expensive, but the need of water is so great that the cost need not be seriously considered.

The following publications of the United States Geological Survey[1] should be read by those who are interested in the construction of wells in the Navajo country:

Slichter, C. S., The California or "stovepipe" method of well construction: Water-Supply Paper 110, 1905; also Water-Supply Paper 140, 1905.

Fuller, M. L., Underground waters for farm use: Water-Supply Paper 255, 1910.

Bowman, Isaiah, Well-drilling methods: Water-Supply Paper 257, 1911.

The types of wells in unconsolidated deposits now in use on the reservations and which are recommended as adapted to the country are (1) dug wells, (2) driven wells, and (3) drilled wells.

DUG WELLS.

Dug wells 3 to 15 feet in depth, sunk along dry stream courses, are in use by both Indians and whites. Many of these wells are

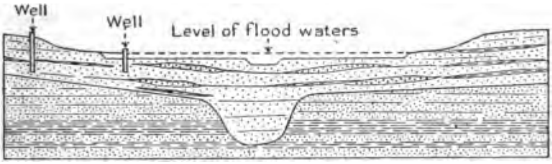


FIGURE 19.—Section of a wash showing location of shallow dug wells.

not curbed or protected in any fashion, being merely holes sunk in the bed of the wash to secure water between rains. It is feasible to curb and protect such wells by brush or stone and to make them

[1] Water-Supply Papers 110, 140, and 255 may be obtained without cost by applying to the Director, United States Geological Survey, Washington; the stock of Water-Supply Paper 257 available for free distribution has been exhausted, but the report is for sale (price 15 cents) by the Superintendent of Documents, Washington, D. C., to whom inquiries should be sent.

permanent. It is better, however, to dig wells on a bank which the shifting current is not likely to remove and to sink them to the level of ground water in the adjoining wash (fig. 19). A rope and bucket with or without a pulley wheel is the best device for raising the water if the well is for the use of the natives. Shallow wells may be dug by an inexperienced Indian, and that wells exceeding 50 feet in depth may be constructed by Indian labor with no other tools than pick and shovel, windlass, and bucket has been demonstrated by Mr. Tom Leadén at the Cornfields School.

The chief obstacle to the rapid and economical construction of shallow open wells is the presence of quicksand, which is likely to be encountered at any depth. It is not to be expected that an Indian can overcome this difficulty; the supervision of a practical farmer or a superintendent with some knowledge of well-drilling or mining is essential. There should be at hand water-tight wooden boxes, or, better yet, sections of iron tile or cement casing so flanged as to make water-tight joints. This protective box may be sunk as digging proceeds, and may be used not only to prevent caving but also to shut off less desirable water where more than one water-bearing bed is found. It should be borne in mind that the pressure exerted by quicksand on well casing is very great; that when saturated with water the lateral pressure of sand is equal to about one-half of the vertical pressure, and that beyond the point of saturation the vertical and lateral pressure are equal. The casing should therefore be strong; it should also be water-tight, for saturated quicksand flows wherever water will flow, passing even through 100-mesh screens. The nature of quicksand and its method of treatment seem to be pretty well understood in this region, but material suitable for casing is not always available.

A well of large diameter is advised, especially in places where the material of the valley wash consists of adobe, quicksand, sand, and gravel, arranged in pockets or beds of irregular shapes, and where consequently it is impossible to predict the position of the precise bed which contains the largest amount and the best quality of water. Dimensions of 8 by 8 feet are recommended for shallow wells, but wells 10 by 20 feet will in most places justify the expense of construction. The mammoth dug wells, 30 feet or more in diameter, used by the Santa Fe Railway are good patterns to follow.

A dug well of special type is in use at Cottonwood Tank, on the road between Tuba and Lee Ferry. The rock floor of a side canyon entering the main wash at this point is coated with gravel to a depth of 5 to 6 feet. A subsurface dam across the narrow canyon tends to accumulate water within the gravels. Back of the dam a well 6 feet deep has been sunk in the gravels, walled with stone, and

provided with a concrete neck, which rises above flood waters. (See fig. 20.) It is believed that this method of construction is applicable to many other places.

At Tohachi 3,000 gallons of water per day is obtained by a combination of well and tunnels. From the bottom of a well sunk on the

FIGURE 20.—Diagram illustrating method of constructing a well in the mouth of a rock canyon filled with coarse alluvium.

bank of an arroyo a tunnel was driven beneath the wash, and the roof of the tunnel was shattered by charges of powder. The construction of this well was in charge of a skilled miner, Mr. Tom Leaden, who believes that additional tunnels at this point would increase the supply of water, and that this method may be successfully applied at a number of other points on the reservation. (See fig. 21.)

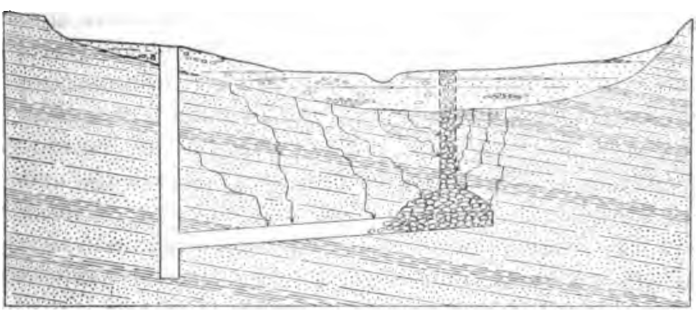


FIGURE 21.—Section illustrating method of obtaining water from the saturated rocks and unconsolidated deposits beneath a wash.

On account of the unwholesome character of water obtained from wells in rock at the Chinle School the construction of a large well in the filling of the Chinle Wash at the mouth of Canyon de Chelly was advised. Test pits indicated a strong underflow and a fluctuation of the water table from a few inches below the surface to 5 feet

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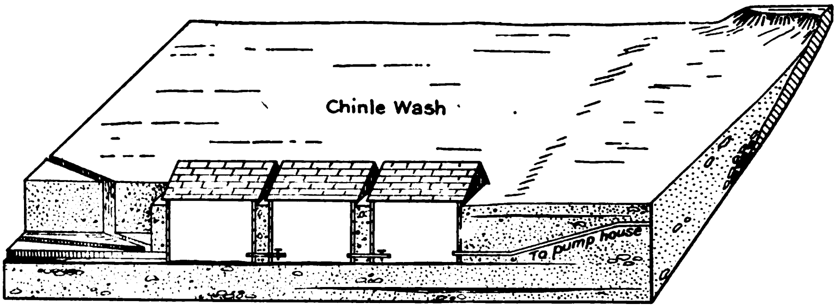

FIGURE 22.—Diagram showing method of recovering ground water from underflow in Chinle Wash.

found. Additional water is collected by laterals leading into the sands of the wash, and the total water is made available by pumping and piping to the points where needed for irrigation. (See fig. 22.)

DRIVEN WELLS.

Water in unconsolidated deposits at depths within the suction limit—about 25 feet from the surface—may be cheaply obtained by driving into the ground pieces of iron pipe to which drive points and strainers have been attached. The pipe used may be of any desired length, as sections may be added as driving progresses. The pipe ordinarily used is 1 to 3 inches in diameter, but larger sizes are recommended for this region. The pipe may be driven with a maul or with a driver operated by machinery. If bowlders are encountered in driving the pipe, they must be removed by blasting or the well must be abandoned. In some parts of the United States the presence of bowlders is such a serious obstacle as to make this method of construction impracticable, but in the washes of the Navajo country large bowlders are rare, and, so far as my knowledge extends, no wells in the district have met with this difficulty. The screen or strainers used must be of such character as to permit water but not sand in appreciable amounts to enter. The particular type of screen used and its length depends on the character of material in which the water is contained. It has been found advisable in the Tusayan Washes and along the Little Colorado, where many wells of this type are to be found, to use a screen with a large number of small holes rather than a smaller number of large openings. The screen commonly used on the cattle ranches along the Santa Fe Railway has 60 to 80 perforations per square inch, but twice that number of openings is advised for the Little Colorado Valley. A long screen section

should be provided. At Holbrook lengths of 6 to 8 feet are common, but screens 60 to 80 feet long are in use in other parts of the country.[1]

In practice it is found advisable to drive two or more pipes near enough together to be connected and pumped as a single well; in this way pipes of smaller size may be used, and the clogging of the screen in one well will not destroy the supply. At Sharp ranch, north of Holbrook, two driven points at each of two wells are connected and pumped by a windmill. One of these wells tested 10 gallons per minute for a 60-hour run. At this place the points are driven into the bottom of a dug well—a method applicable wherever the water table is more than 25 feet below surface. It should be noted that driven wells obtain surface water which is liable to be contaminated by harmful substances that may lie on the ground near the well; the area immediately adjoining the well should be fenced, therefore, to exclude stock. It is advisable to test water at different horizons by attaching hand pumps to the top of the pipe, for it is possible in wells of this type to exclude water of poor quality occurring at definite horizons. Driven wells are inexpensive; they require no special machinery for their construction. In the porous sands of the larger washes and on the flood plains of the Little Colorado and the San Juan, where the water table is near the surface, wells of this type are satisfactory. Their chief disadvantage lies in the fact that pipes of large diameter are sunk with difficulty. Where permanency of flow and a considerable volume of water are considerations of prime importance wells of other types are more likely to meet the requirements.

DRILLED WELLS.

The chief advantages possessed by drilled wells, compared with driven wells, are greater depth and larger diameter. Any one or all of the water-bearing beds found in unconsolidated deposits may be tapped by drilled wells, regardless of depth. Such wells may also be more readily protected from surface pollution. A portable rig is required—a rig equipped with percussion drill and capable of going to depths of 100 feet or more. Standard screw casing appears to be best adapted for use in wells of this region, but for large wells sunk to moderate depths "stovepipe" casing is recommended on the ground of economy. Wells of large diameter are advised for the Navajo Reservation—6, 8, or 12 inch holes are preferable to those of smaller diameters. Such wells are more easily cleaned, and they afford opportunity for the insertion of a gravel screen where the water is encountered in fine sediments. The strainer should be long

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and selected with reference to the nature of the water-bearing bed. In the wells at Leupp, gauze with 90 and 100 perforations per square inch is used, and the driller is of the opinion that much finer screens would give better results.

Pumps driven by hand, by wind, by horsepower, or other means may be installed at the wells. Windmills are recommended, pro-

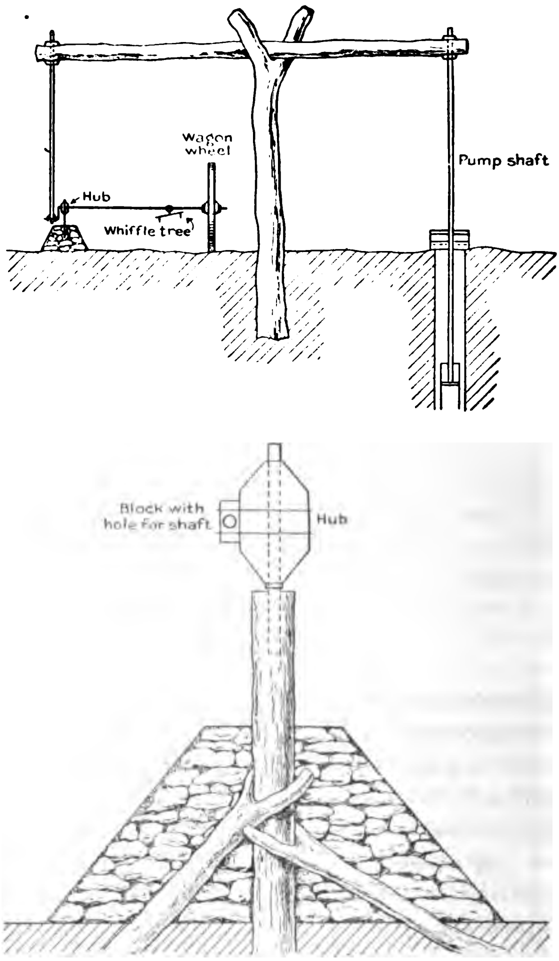


FIGURE 23.—Homemade horsepower pump.

vided they are placed in charge of an official. The Indians at present are incapable of repairing windmills or even hand pumps. The windmill selected for use in this country should be of simple design, easy to erect, and easy to move, and the gears should be either protected or replaceable at slight cost, for the life of gearing exposed to severe sand storms is short. Mr. H. F. Robinson, of the Indian

Office, has devised a pump which is to be driven by horsepower and which may be constructed without much expense from materials usually found lying about stores, ranches, and Government headquarters. Such a pump, drawn from sketches by Mr. Robinson, is shown in figure 23.

After a preliminary examination of the Hopi Reservation in 1909 drills were set at work at Leupp and along the Tusayan Washes and 28 wells have been sunk to depths of 20 to 118 feet. About half of them found no water or water held so tightly in fine sands that only minute quantities could be recovered. The other wells have been equipped with windmills and are proving serviceable.[1]

The difficulties encountered in drilling these wells were due chiefly to quicksand, which would have been equally troublesome to any other method of construction.

WELLS IN BEDROCK.

Bare rock lies at or near the surface over so large a part of the Navajo country that wells are desired in many places where groundwater storage reservoirs of sand and gravel are absent. Wells 3 to 6 feet deep sunk at points where cracks and pores of the rock are known to contain water, present no uncertain elements. The Bidahochi well, for instance, collects water circulating in sandstone within 5 feet of the surface and gives a small permanent supply where previously there was only a seep which yielded no water during the rainless months. At other points where fresh or alkaline seeps of fluctuating volume emerge from ledges a well in rock a short distance back of the seep may serve to recover water now lost by evaporation and to furnish a perennial supply. Such places were noted in the central part of Monument Valley, at Howell Mesa, and at several points on Black Mesa, the Chuska Mountains, and Dutton Plateau. Shallow wells in rock should be several feet in diameter and may be constructed by hand with pick and blasting powder. Where bedrock is covered with alluvial sediments the conditions for supplying water to the cracks and cavities in the ledge are favorable and wells sunk in unconsolidated sediments often may be improved in yield by continuing the drill for 5 to 10 feet into rock.

In selecting well sites where water is to be recovered from bedrock the following facts should be kept in mind:

1. The water in rocks occurs primarily in joints and cracks and bedding planes, and to a less degree in spaces between the grains and pebbles of which the rock is composed. Other things being

[1] To July 1, 1914, 140 wells had been drilled on the Navajo and Hopi reservations, including wells in unconsolidated deposits and in rock. Of these, 72 are reported satisfactory; 68 are failures because of lack of water, quality of water, or presence of quicksand.

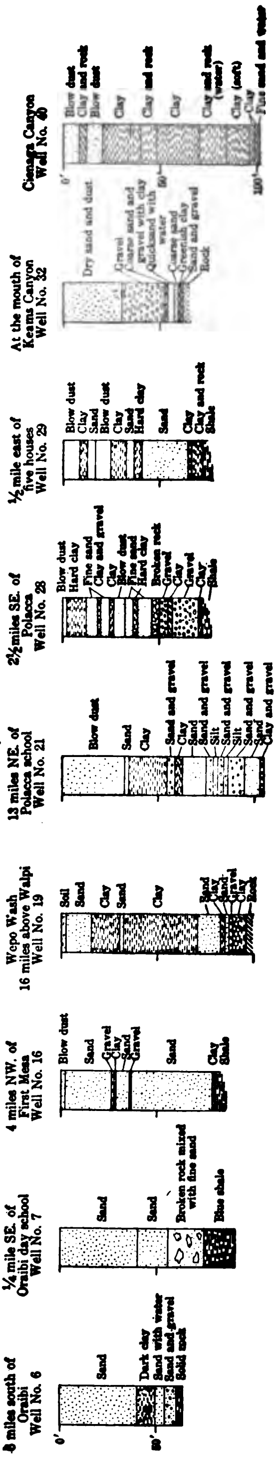


FIGURE 18.—Sections of wells in unconsolidated deposits, Tusayan Washes.

At Douglass Camp, in Monument Valley, two wells, 10 and 12 feet deep, have rock bottoms covered 2½ feet deep with water. The water used at Wide Ruin is obtained from a well 15 feet in depth in which the water stands throughout the year at about 6 feet below the surface. It is near the head of a narrow canyon, whose floor is covered with sand and gravels, partly cemented. This well was utilized some hundreds of years ago by the people who occupied the walled inclosure and fragmentary pueblos now known as Wide Ruin. No trace of a well was found when the white man first visited these ruins, but excavation revealed one 16 feet square, walled with flat slabs of stone and with a flight of stone steps leading to the water. The well at the Navajo sawmill is dug in the alluvial fill of a flat swale near the head of a rock-walled canyon. The water rests on the rock beneath the sands, at a depth of 14 feet. A well sunk in rock, near at hand, yields no water.

The position of all the wells mentioned was determined by the presence of seepage at points farther down the valley. Without the guidance of such seeps or of alkali flats, or at least moist ground, wells in high valleys can not be located with assurance of success.

WELLS IN THE TUSAYAN WASHES.

The Tusayan Washes include four large channels: Jadito, First Mesa (Polacca), Oraibi, and Dinnebito, in addition to numerous tributaries, all of which combine to carry the run-off from the larger part of Black Mesa. Their drainage areas are: Jadito, 623 square miles; First Mesa, 672 square miles; Oraibi, 652 square miles; Dinnebito, 812 square miles. The average rainfall over this area is probably less than that at Keams Canyon (10.94 inches), for,

although the precipitation on Black Mesa may be 12 or 13 inches a year, the lower portions of the washes probably receive less than 8 inches. By assuming a mean annual precipitation of 9.5 inches we find that the water which falls within the drainage basins of the Tusayan Washes amounts to about 1,400,000 acre-feet a year. The Oraibi Wash alone collects each year 330,000 acre-feet, and First Mesa Wash 340,000 acre-feet. These washes are filled to depths of 10 to 90 feet with adobe, silt, and fine sand, with smaller amounts of coarse sand and gravel. The average porosity of these materials is not far from 25 per cent. Moreover, though the gradient of the washes is about 25 feet to the mile, long stretches drop less than 10 feet in a mile, and other sections of their courses are so flat that lakes covering hundreds of acres are formed during flood seasons. It thus appears that opportunities for filling the ground-water reservoir are favorable. Springs are rare along these washes, and the conditions for construction of storage reservoirs are not good; it was therefore decided to explore this area for underground water. Oraibi and First Mesa washes were selected for study and drilling was begun in 1910. During the two following years 29 wells were sunk in localities chosen to give the largest amount of information regarding the conditions under which water occurs in alluvial fill. Logs of nine of these wells are given in figure 18.

Five wells were sunk in the lower Oraibi Wash on a low-grade fan deposited by ephemeral streams. The materials of the fan were known to be fine and very irregularly distributed, but it was hoped that lenses of gravel were included, and that a water horizon would be encountered between the unconsolidated cover and bedrock. Neither of these expectations was realized. The silt was found to be excessively fine, "blow dust" of the drillers, and though saturated dust and moist sand were encountered no water was fed into the well. It would appear that the silt and adobe distributed as lenses was able to prevent both horizontal and vertical percolation. In fact, some of the material is so fine that it might be safely used in the construction of earth dams. The upper 28 feet of a drill hole, sunk by hand during June, 1909, gave the following typical section:

Section of hand-drilled hole, lower Oraibi Wash.

	Thickness.	Depth.
	Feet.	*Feet.*
Wind-blown sand	2	2
Hard-packed adobe	6	8
Fine red clay rendered soft by water	1	9
Very fine, hard-packed sand	3	12
Coarse sand	1	13
Adobe, white, dry	5	18
Very fine sand, moist	4	22
Clay and very fine sand, moist	6	28

In all wells sunk moist sand was encountered between depths of 6 to 30 feet, below which point the materials encountered were generally dry and hard packed.

In the upper Oraibi Wash a well 6 miles south of Oraibi and one at the Day School recovered 500 gallons an hour each, the largest flow coming from the bottom sands overlying bedrock. Two shallow wells near the base of the mesa at Bacobi were abandoned because the supply was insufficient to justify the installation of windmills.

In the open floor of the First Mesa Wash five successful wells yield from 300 gallons an hour to "more than the pump could pull," obtained at depths exceeding 100 feet. Two other wells were abandoned at 46 feet and 60 feet, respectively, on account of quicksand.

Along the upper Wepo and upper First Mesa washes, where the alluvial fill consists of coarser material, the five test wells encountered rock at depths between 80 and 102 feet. The largest amount of water was discovered between 57 and 85 feet. Five wells were sunk at Five Houses, all of them reaching rock at depths between 52 and 84 feet. Four of these wells obtained water in quantities insufficient to encourage development; the fifth, less than a mile distant from the dry holes, discharged on a test run 350 gallons per hour. No better demonstration of the sporadic distribution of water-bearing beds need be desired.

In Cienega Canyon, a tributary of Keams Canyon, nine wells were driven a short distance apart. The records at hand for six of the wells show that the water from five could not be developed "on account of fine sand," and that the sixth well, 80 feet deep, obtains 400 gallons an hour of water from a bed of sand 60 feet below the surface.

The results of drilling in the Tusayan Washes, combined with the knowledge obtained from the wells sunk in Leroux and Cottonwood washes, justify the expense of exploratory work in all the larger washes on the reservations where water is desired. Failures are, however, to be expected, and the most serious problem confronting the driller is the proper treatment of quicksand. If suitable strainers can be devised the number of "dry" wells may be greatly reduced.

CONSTRUCTION OF WELLS.

THE PROBLEMS.

Among the problems confronting the well maker working in unconsolidated sediments of the Navajo country are the following:

1. Excessively fine sand, "blow dust" in the driller's parlance, may be expected in all holes. This dust caves readily and when moist flows with ease. Though often found in saturated condition, its waters are held tight by capillarity.

2. "Quicksand" is an almost universal accompaniment of sands and gravels in washes.

3. Water is contained in lenses of sand, gravel, and bowlders which are sporadically distributed both horizontally and in vertical section.

4. Alkali water, salt water, and fresh water occur in "streaks" at various levels and at unknown distances apart.

5. Except at school and agency sites, the well is to be used by the Navajo, Hopi, or Piute, people who know little about pulley wheels, who can not repair a pump or windmill, and to whom an engine is a mystery.

6. Fuel for operating drills is practically absent from the large washes; water is scarce and supplies must be obtained from distant points. Wells therefore are expensive, but the need of water is so great that the cost need not be seriously considered.

The following publications of the United States Geological Survey[1] should be read by those who are interested in the construction of wells in the Navajo country:

Slichter, C. S., The California or "stovepipe" method of well construction: Water-Supply Paper 110, 1905; also Water-Supply Paper 140, 1905.

Fuller, M. L., Underground waters for farm use: Water-Supply Paper 255, 1910.

Bowman, Isaiah, Well-drilling methods: Water-Supply Paper 257, 1911.

The types of wells in unconsolidated deposits now in use on the reservations and which are recommended as adapted to the country are (1) dug wells, (2) driven wells, and (3) drilled wells.

DUG WELLS.

Dug wells 3 to 15 feet in depth, sunk along dry stream courses, are in use by both Indians and whites. Many of these wells are

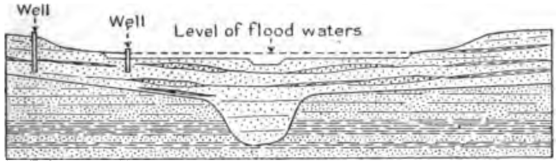


FIGURE 19.—Section of a wash showing location of shallow dug wells.

not curbed or protected in any fashion, being merely holes sunk in the bed of the wash to secure water between rains. It is feasible to curb and protect such wells by brush or stone and to make them

[1] Water-Supply Papers 110, 140, and 255 may be obtained without cost by applying to the Director, United States Geological Survey, Washington; the stock of Water-Supply Paper 257 available for free distribution has been exhausted, but the report is for sale (price 15 cents) by the Superintendent of Documents, Washington, D. C., to whom inquiries should be sent.

permanent. It is better, however, to dig wells on a bank which the shifting current is not likely to remove and to sink them to the level of ground water in the adjoining wash (fig. 19). A rope and bucket with or without a pulley wheel is the best device for raising the water if the well is for the use of the natives. Shallow wells may be dug by an inexperienced Indian, and that wells exceeding 50 feet in depth may be constructed by Indian labor with no other tools than pick and shovel, windlass, and bucket has been demonstrated by Mr. Tom Leadén at the Cornfields School.

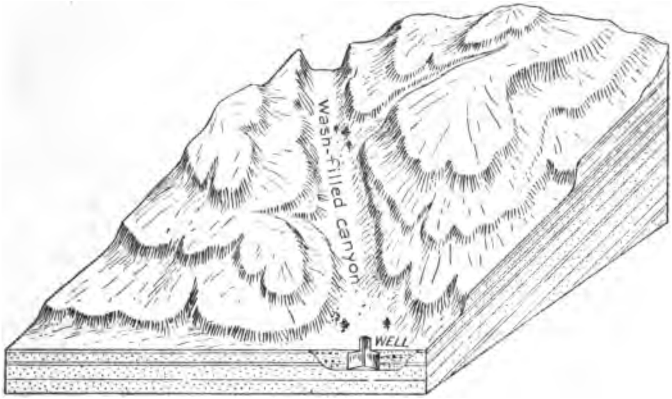
The chief obstacle to the rapid and economical construction of shallow open wells is the presence of quicksand, which is likely to be encountered at any depth. It is not to be expected that an Indian can overcome this difficulty; the supervision of a practical farmer or a superintendent with some knowledge of well-drilling or mining is essential. There should be at hand water-tight wooden boxes, or, better yet, sections of iron tile or cement casing so flanged as to make water-tight joints. This protective box may be sunk as digging proceeds, and may be used not only to prevent caving but also to shut off less desirable water where more than one water-bearing bed is found. It should be borne in mind that the pressure exerted by quicksand on well casing is very great; that when saturated with water the lateral pressure of sand is equal to about one-half of the vertical pressure, and that beyond the point of saturation the vertical and lateral pressure are equal. The casing should therefore be strong; it should also be water-tight, for saturated quicksand flows wherever water will flow, passing even through 100-mesh screens. The nature of quicksand and its method of treatment seem to be pretty well understood in this region, but material suitable for casing is not always available.

A well of large diameter is advised, especially in places where the material of the valley wash consists of adobe, quicksand, sand, and gravel, arranged in pockets or beds of irregular shapes, and where consequently it is impossible to predict the position of the precise bed which contains the largest amount and the best quality of water. Dimensions of 8 by 8 feet are recommended for shallow wells, but wells 10 by 20 feet will in most places justify the expense of construction. The mammoth dug wells, 30 feet or more in diameter, used by the Santa Fe Railway are good patterns to follow.

A dug well of special type is in use at Cottonwood Tank, on the road between Tuba and Lee Ferry. The rock floor of a side canyon entering the main wash at this point is coated with gravel to a depth of 5 to 6 feet. A subsurface dam across the narrow canyon tends to accumulate water within the gravels. Back of the dam a well 6 feet deep has been sunk in the gravels, walled with stone, and

provided with a concrete neck, which rises above flood waters. (See fig. 20.) It is believed that this method of construction is applicable to many other places.

At Tohachi 3,000 gallons of water per day is obtained by a combination of well and tunnels. From the bottom of a well sunk on the



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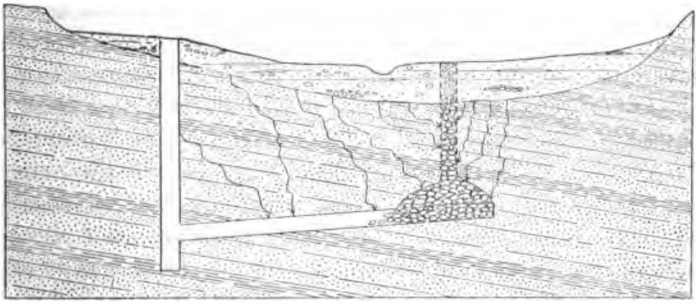

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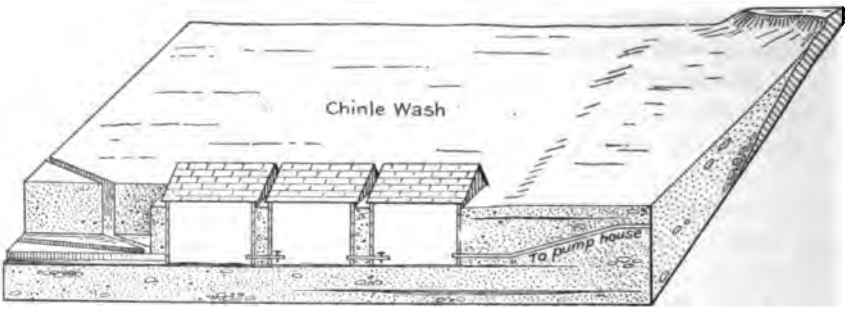

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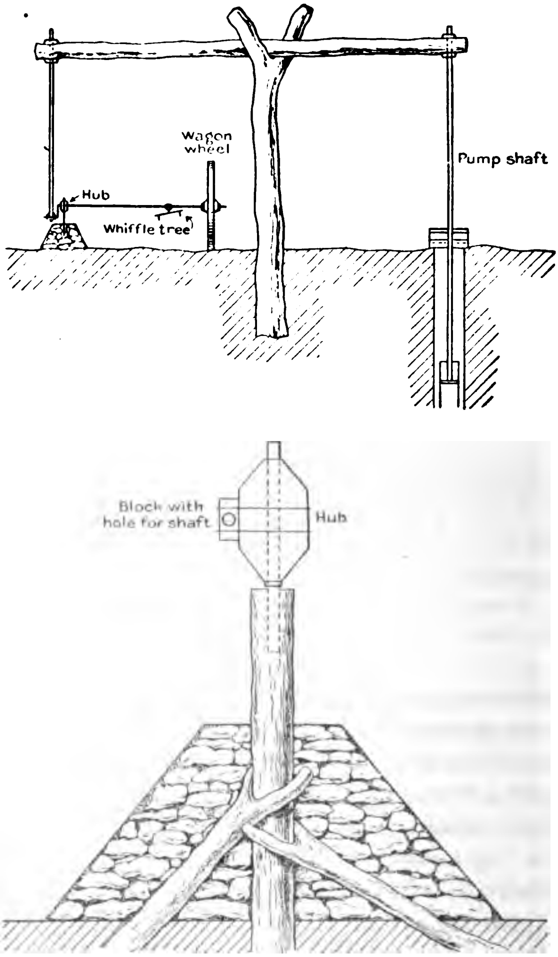

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[1] To July 1, 1914, 140 wells had been drilled on the Navajo and Hopi reservations, including wells in unconsolidated deposits and in rock. Of these, 72 are reported satisfactory; 68 are failures because of lack of water, quality of water, or presence of quicksand.

equal, the most fractured ledge contains the most water, and for this reason the capacity to hold water is greater along the Defiance monocline, along Comb Ridge, and about Navajo and Carrizo mountains than on Black Mesa and Moenkopi Plateau. As to type of rock, limestones hold water only in joints; sandstones carry water in pore spaces as well as in joints; shales contain little water in a form to be recovered. The well sunk 300 feet into Mancos shale at Oraibi yields no water, and the supply from a 165-foot well in shales of Moenkopi formation at Allentown is insignificant.

2. A rock stratum may have the capacity for holding water and yet be dry because its water is naturally drained away. The water which percolates into bedrock on the highlands may find its way to the face of a mesa, where it appears as a spring or a seep or is lost through evaporation. Elsewhere water may find its way underground to lower valleys, where it is buried beneath thick deposits of alluvial wash at depths too great for recovery. This is especially likely to occur where sedimentary strata have a strong dip and where water moves along planes of stratification. In the San Juan oil fields, at Goodridge, sandstones on anticlines are dry, but the same strata yield water in the syncline; and at Cross Canyon, where a well was sunk 285 feet into porous sandstones and shales without finding water, the water appears to drain not only downward through cracks but also into sloping bedding planes and into near-by canyons. On the other hand, the Navajo sandstone and the Chuska sandstone are so porous and possess such irregularity of jointing and of secondary bedding that water may be found at unexpected places or be absent where conditions are apparently favorable. Also, the flat-lying sandstone of the Mesaverde formation of Chaco Plateau, composed of alternating strata of porous sandstone and of shale, and jointed at more or less regular intervals, has yielded water at almost every locality where wells have been drilled. The Dakota sandstone, likewise, has a good reputation as a water bearer.

3. The quality of water from wells in rock varies with the type of rock and the conditions under which it was laid down. The wells sunk in the Moenkopi formation at Allentown and Adamana yielded poor water. Likewise the wells in shales of the Chinle formation at the Chinle School and farther up the Chinle Valley are alkaline to a harmful degree. On account of the liability to obtain water of unsatisfactory quality and also because of the small yields to be expected, wells are not advised in the Moenkopi formation, the Chinle formation, nor the Mancos shale. The Shinarump conglomerate, the Wingate, the Navajo, the Dakota, the Mesaverde, and the Chuska formations offer better prospects.

In order to determine the amount of available water in the various rock formations represented on the reservation, sites were suggested

for exploratory drilling. In pursuance of this plan five wells have been sunk in the Chinle formation of the upper Chinle Valley; one in the same formation, in Sabito Canyon, a tributary to the Pueblo Colorado; one at the Cornfields; and one through the entire thickness of Cretaceous strata at Keams Canyon. Of the wells in rock of the Chinle formation one obtained 400 gallons per hour at the top of the first shale encountered, and the Cornfields well was discontinued after finding 190 gallons an hour in sands before bedrock was reached. Of the remaining five wells, one is dry and four yielded satisfactorily. As was to be expected, the water from strata of the Chinle was more or less alkaline, and for this reason the Sabito well has been abandoned and one of the other wells is suitable only for stock. It is to be hoped that the original plan of sinking these wells entirely through the Chinle formation to the Shinarump conglomerate may be carried out, for by so doing the prospect of obtaining supplies of excellent water would be improved. A log of one of the wells in Chinle Valley is shown in figure 24.

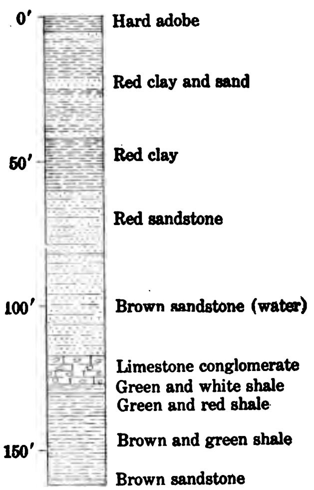


FIGURE 24.—Section of well in Chinle Valley.

The Keams Canyon well is located near the south edge of Black Mesa. A deep bore was advised at this place for two reasons: First, because the conditions here are typical for the territory between Salahkai Mesa and Oraibi Butte, a distance of 100 miles, and therefore the results of this test well would serve as a guide to the location of other expensive wells; and second, the prospects were reasonably good for obtaining water from the Dakota sandstone at a depth of approximately 1,000 feet. The reported results of the drilling are these: After passing through 1,070 feet of Mancos shale the drill penetrated 50 feet of brown and gray sandstone. The hole was continued to 1,288 feet through light-red and white sandstone, green and white shales, and "chalk or limestone." In this section (fig. 25) the strata between 1,070 and 1,120 feet are believed to represent the Dakota, here, as in many other places, consisting of a fine-grained brown sandstone. A small flow issued from this rock and rose under artesian pressure to a point 200 feet below the surface. Because of the variable nature of the Dakota the Keams Canyon well does not furnish conclusive evidence that similar wells

at First Mesa, Second Mesa, Oraibi, and intervening points will be unsuccessful; it demonstrates that wells can not be sunk with assurance of obtaining large supplies of flowing water at the Dakota horizon.

The sinking of wells in the rocks of the Navajo country presents no special difficulties, and may be accomplished by any standard drilling method.

ARTESIAN WELLS.

ESSENTIAL CONDITIONS.

Water which rises above the level where struck in the well is said to be "artesian," whether it rises to the surface or remains at some level below the surface. The name "flowing well" is applied to a well in which the water overflows in the form of a continuous stream.

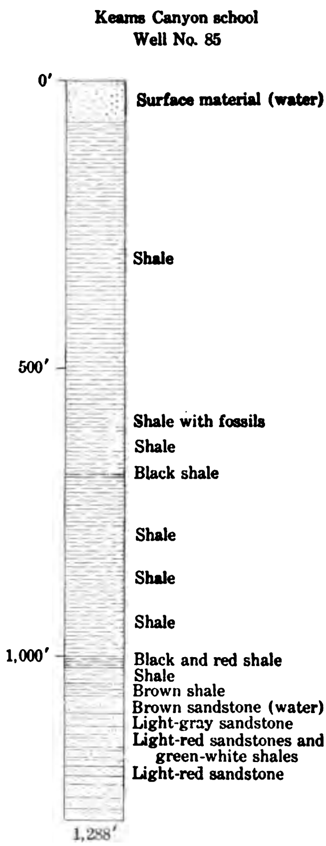


FIGURE 25.—Section of well in rock at Keams Canyon.

The arrangement of strata which favors the accumulation of artesian waters is as follows: (1) A porous stratum, part of which enters the ground with a dip sufficient to carry it beneath other strata; (2) an impervious stratum which lies above the porous stratum and which serves to prevent or retard the upward percolation of water; and (3) an impervious bed beneath the sloping, porous bed, and which tends to confine the waters within a certain zone. This underlying bed is an advantageous but not an essential element. If the porous bed is not so placed at the surface as to receive a supply, no water may be stored even if the rock has a large water-bearing capacity. Likewise if the overlying bed of impervious materials is fractured, water may escape from confinement and rise to higher levels, thus releasing the pressure. The best unconsolidated materials for the confining bed are clay, adobe, or extremely fine sands; and the most desirable rock strata are shale and dense limestone. The porous water-bearing beds are usually sands and gravels, or, among rocks, sandstones and conglomerates.

The conditions attending the occurrence of artesian water may be illustrated by sections of wells at St. Michaels and at Gallup, the

former in sands and clay, the latter in sandstones and shales (figs. 26 and 27). On the Navajo Reservation the geologic structure is favorable for artesian water at several localities both in unconsolidated sediments and in bedrock.

WELLS IN UNCONSOLIDATED DEPOSITS.

Springs and seeps issuing from the lower margin of the long flat slopes which border the washes indicate the presence of water within the unconsolidated materials filling the valleys. In the sands of the upper slopes water stands at a higher level than at points along the valley axis and opportunity is afforded for absorption of rain-

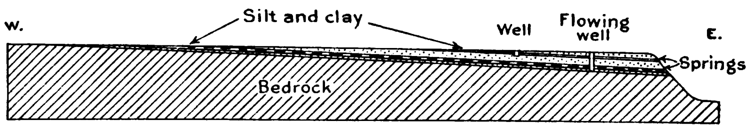


FIGURE 26.—Diagram illustrating occurrence of artesian water at St. Michaels, Ariz.

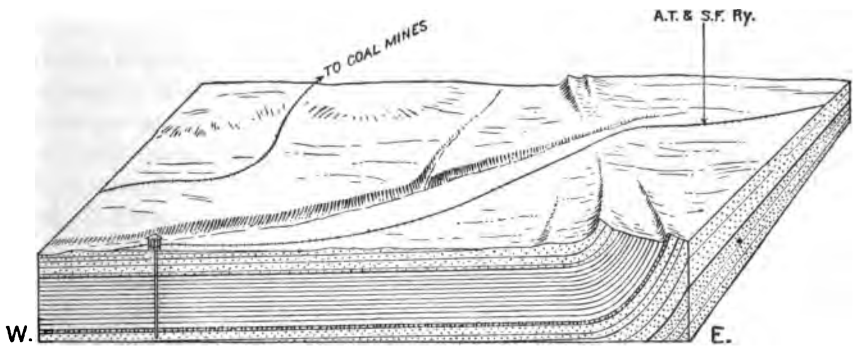


FIGURE 27.—Diagram illustrating occurrence of artesian water at Gallup, N. Mex.

fall by the porous alluvium. If beds of impervious clay or adobe were regularly interstratified with layers of gravel and sand, conditions for flowing wells would be ideal. The water-bearing beds are, however, covered with strata which are not absolutely water-tight, and the ground water is therefore continually escaping. Moreover, the alluvial strata which together form the valley fill are not continuous from the rim to the center of a valley, and the flow of ground water is consequently highly irregular both in volume and direction. In the deep wells sunk in unconsolidated deposits of Oraibi and First Mesa washes water rises above the point where it is struck but does not overflow. It is entirely probable that flowing wells will from time to time be found as more holes are drilled.

WELLS IN BEDROCK.

The storage of artesian water is facilitated by couplets of strata in which beds of shale overlie beds of porous sandstone. Given this stratigraphic arrangement, artesian water may enter and be retained in sedimentary rocks, provided the strata have suitable dip and the water-bearing bed is so exposed as to absorb the rainfall. In the Navajo country the Dakota sandstone and Mancos shale form a suitable couplet, and the number of springs issuing at this horizon demonstrates the presence of water confined in rocks beneath Black Mesa and Dutton and Chaco plateaus. The Shinarump conglomerate, together with the De Chelly sandstone contains water which is prevented from escaping upward by the shales of the Chinle formation, and the alternating beds of shale and sandstone within the Mesaverde formation also furnish favorable conditions for artesian waters. Within the area of Carboniferous strata on San Juan River, the massive limestones act as the confining beds and retain the waters under pressure in the sandstones lying immediately underneath.

FALLACIES REGARDING ARTESIAN WATERS.

It is but natural that the presence of flowing wells in an arid region should give rise to various opinions regarding origin and method of flow. With the more fantastic views, for example that the deep-seated waters on the Navajo Reservation are in some way connected with volcanic eruptions at San Francisco Mountain and Mount Taylor, and that the wells intercept an underground flow from the San Juan and the Colorado, we need have nothing to do. Certain other erroneous conceptions, however, have direct bearing on the plans for water development and should be briefly considered.

1. There is a prevalent belief that when water discovered in unconsolidated deposits rises in the well, a hole drilled into rock at the same place will produce a flowing well. In answer to this opinion it need merely be stated that the conditions determining the presence of artesian water in sands and clays have no known relation to the conditions controlling the distribution of water in bedrock.

2. That when artesian water is struck in a well more water with a stronger flow is to be found some distance below. It should be remembered that artesian water occurs at fairly definite horizons and that after these horizons are passed water may not be found at all until the next horizon is penetrated. In some formations, for example the Mesaverde, there are several water horizons separated by 50 to 200 feet; in other formations, the horizons are many hundreds of feet apart. In certain situations no water is likely to be encountered below a given stratum, regardless of the depth to which the well is sunk.

3. That when artesian water is struck at a certain depth wells for miles about may obtain water at the same depth. The fallacy of this view is evident when it is recalled that strata may not be horizontal and that a water-bearing stratum encountered at 600 feet may lie 1,000 or 2,000 feet below the surface in a neighboring township.

4. That when it has once been demonstrated that water occurs in a sedimentary formation, that particular formation may be relied upon to yield water wherever encountered. In a limited sense and for an area of uniform arrangement of strata this opinion is well founded. Strata, however, are rarely continuous in structure, thickness, and composition for many miles, and in many formations not for many hundreds of feet. The Dakota sandstone is perhaps the most persistent water carrier in the Rocky Mountain and Plateau provinces, yet it is not everywhere present and even where present, it may not furnish water. At Gallup a strong flow was obtained, presumably from this formation, but in the well at Keams Canyon only a slight trickle appeared.

5. There is a widespread belief that water from a flowing well is inexhaustible. That this view is contrary to fact can not be too strongly expressed. The water comes from a reservoir which though replenished from time to time may be exhausted. Disastrous experiences in artesian areas in California and elsewhere should in themselves be sufficient to induce the owners of flowing wells to allow no water to run to waste. The wells should be capped when not in use.

ARTESIAN AREAS.

Determining factors.—Flowing water has been obtained by a few wells in the Navajo country but so far not within the borders of the Navajo and Hopi reservations proper. Consequently the belief that certain areas afford conditions favorable for artesian water is based solely on a knowledge of the geologic structure of the region. Moreover, the geologic investigation was of a reconnaissance nature only. The composition of the sedimentary rocks has been determined with a fair degree of accuracy, the thickness of the formations has been determined for a few places, and the attitude of the strata has been roughly measured over a large part of the area. There remain, however, so many undetermined factors regarding geologic boundaries and details of structure, composition, and texture, that the description of the various "artesian areas" is presented as suggestive rather than definitive. The sections designed to illustrate artesian areas are necessarily generalized, for they are based on reconnaissance topographic maps on a scale of 4 miles to the inch, with contour intervals of 200 and 250 feet. It is believed, however,

that the accompanying illustrative sections (Pl. XXIX) will serve a useful purpose in directing exploration for artesian water which, if discovered, will be of inestimable value to the Indian inhabitants whose lot has been cast in this neglected portion of the public domain.

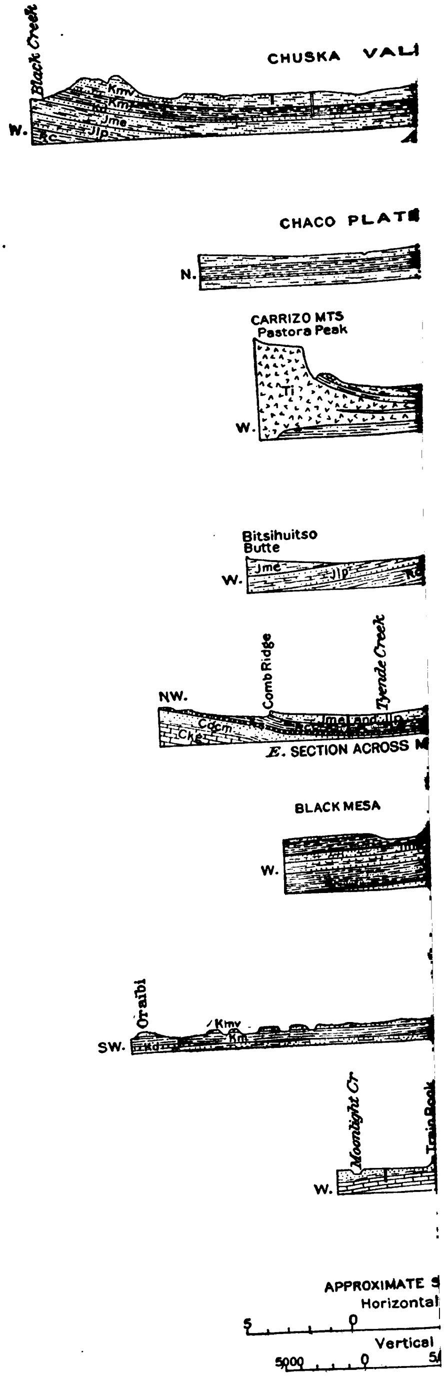
Upper Chuska Valley (*section A*).—The collecting ground for the deep-seated waters in the upper end of Chuska Valley is the eastern and northern edge of Manuelito Plateau, the eastern slope of Black Creek Valley, and the southeastern base of Chuska Mountain. Water should be sought in the Mesaverde formation where alternating beds of shale and sandstone afford favorable conditions for zones saturated with artesian water. Wells in this formation should be sunk to depths between 600 and 1,200 feet. Deeper waters may occur in the Dakota sandstone at depths exceeding 1,400 feet.

Dutton Plateau and southern Chaco Plateau (*section B*).—In the transverse valley forming the center of Dutton Plateau water may be recovered from the Dakota sandstone by wells sunk through the Mancos shale to depths of 200 to 800 feet. North of Crown Point wells may procure water from the sandstone of the Mesaverde formation at depths of 200 to 800 feet. Since I began my work in this region several successful wells have been developed on this portion of the plateau, in all of which water is under artesian pressure, and one at least of the wells flows at the surface. Artesian water is likely to be found also in the Dakota sandstone at a depth of 1,600 to 2,000 feet. The collecting area for waters in both the Dakota and the Mesaverde formations is Dutton Plateau and the highlands of north-central New Mexico. Sections of three wells in this area are shown in figure 28.

Lower Chuska Valley (*section C*).—Waters falling on the eastern slopes of Carrizo Mountain percolate downward to some extent into the Dakota sandstone, the McElmo formation, and the La Plata group of sedimentary rocks. Wells sunk to the Dakota in the area between Red Wash and Hogback Mountain are likely to encounter artesian water at depths between 400 and 1,000 feet. There is also a prospect of obtaining flowing water from the La Plata sediments at a minimum depth of 1,000 feet.

Upper Chinle Valley (*section G*).—The floor of the Upper Chinle Valley is carved in rocks of the Chinle formation, parts of which are known to contain water but not under artesian pressure. Beneath the shales and limestones of the Chinle formation is the Shinarump conglomerate, which on Defiance Plateau is suitably displayed for the absorption of water. It is probable that wells sunk to depths of 500 feet in Beautiful Valley and 1,600 feet to 2,000 feet in Chinle Valley will tap artesian supplies.

Middle Chinle Valley (*section D*).—The Shinarump conglomerate with the De Chelly sandstone is widely exposed on Defiance Plateau


Black Creek
CHUSKA VAL
Kmv
Km
Kd
Jme
Jlp
W.
CHACO PLAT
N.
CARRIZO MTS
Pastora Peak
Ti
W.
Bitsihuitso
Butte
Jme
Jlp
W.
NW.
Comb Ridge
Tyende Creek
Cdcm
Cke
Jme and Jlp
E. SECTION ACROSS
BLACK MESA
W.
Oraibi
Kmv
Km
Kd
SW.
Moonlight Cr
W.
APPROXIMATE
Horizontal
5
0
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SECTIONS S

north of Canyon del Muerto. Where these strata pass beneath the Chinle formation it is probable that water is confined under artesian pressure, and may be recovered by bore holes 400 to 1,000 feet deep.

Middle Tyende Valley (section E).—Back of Comb Ridge the De Chelly sandstone capped by Shinarump conglomerate is widely

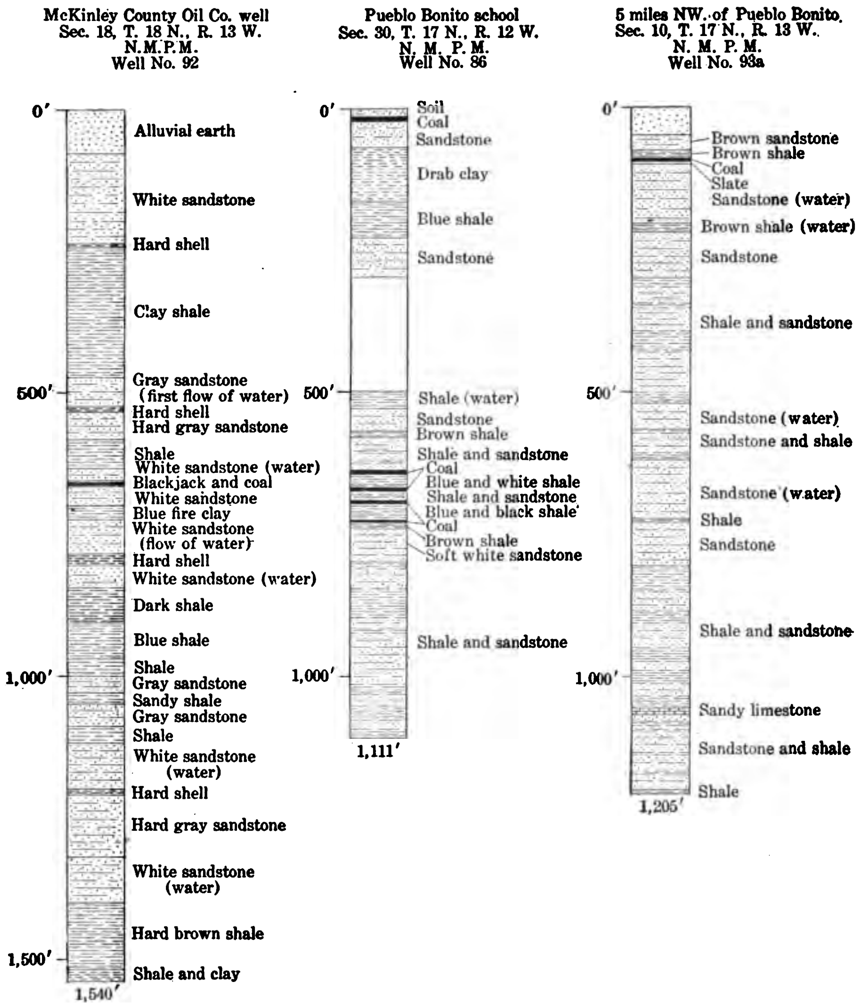

FIGURE 28.—Well sections, Chaco Plateau.

displayed on the southeastern limb of the Monument Valley anticline and trenched by numerous canyons. Water absorbed by these rocks is believed to pass southeastward and eastward beneath Tyende Valley. To reach these artesian waters wells 1,000 to 1,400 feet deep would need to be sunk.

Monument Valley (*section I*).—Monument Valley is the stripped portion of an anticline on which are spread out sediments of Permian (?) age. On the flanks of the anticline are tilted strata of the Shinarump and Chinle formations. Water occurs in the Moenkopi; but unless a thick sandstone member of this formation is struck the quality of the water is likely to be unsatisfactory. The Shinarump conglomerate may probably be reached in upper Moonlight Valley by wells 300 to 600 feet deep. On the eastern limb of the anticline sandstones of the Goodridge formation are brought near enough to the surface to be within reach of wells. North of the San Juan several abandoned oil wells in the Goodridge beds have turned out to be flowing wells of oily water.

Black Mesa (*section H*).—The Cretaceous strata forming Black Mesa are arranged as a flat syncline, the axis of which dips southward from the northern margin of the mesa. The edges of the strata are abruptly terminated by the walled fronts of the projecting headlands on which the Hopi villages are set. Two water horizons are indicated by lines of springs, one between the Mesaverde and the Mancos formations, the other at the base of the Dakota sandstone. Artesian water is likely to be struck in the Mesaverde over the less broken portions of the plateau at depths in rock of 400 to 800 feet. The Dakota extends underneath Black Mesa but is thin and patchy, and in places wanting, and, moreover, has a small exposure on the front facing Tyende Valley. A test well sunk at Keams Canyon entirely through the Mancos shale found the Dakota represented by a thin bed of sandstone containing only minute quantities of water. This well is believed to demonstrate the unreliability of the Dakota sandstone as a water carrier of prominence for the Tusayan area. (See p. 175.)

Gothic Mesas (*section F*).—Six wells sunk near together at Bluff on the north bank of the San Juan, four of them 800 feet deep, the other two 1,085 and 1,165 feet deep, respectively, obtain flowing water at horizons probably the equivalent of the Wingate sandstone at depths of 800 feet and less. Small amounts were obtained from sandstones, probably in the Chinle formation, at greater depths (fig. 29). The conditions for the recovery of artesian water are unusually favorable at this locality, as the porous sandstones of the La Plata group are widely exposed and the strata dip toward the San Juan area from three directions, thus constituting an underground basin. It is believed that equally favorable conditions exist south of the San Juan over the northwestern part of the Gothic Mesas province, and that wells 1,000 to 1,500 feet deep may be expected to yield artesian water.

Other areas.—On the Kaibito Plateau the conditions determining the positions of springs are also favorable for the occurrence of

artesian water at depths between 400 and 800 feet. (See pp. 143–146 and fig. 17.) A well at Gallup, 1,241 feet deep, sunk to obtain water for the use of the Santa Fe Railway, obtained a flow of 4 gallons a

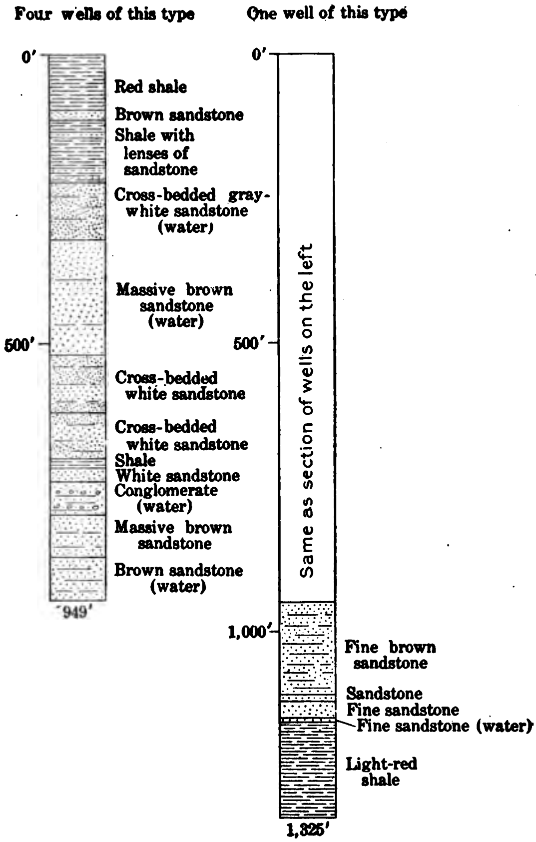

FIGURE 29.—Sections of flowing wells at Bluff, Utah.

minute, and a 305-foot boring at Adamana yields salt water from Moenkopi beds at the rate of 25 gallons a minute.

RECORDS OF WELLS.

Records of wells sunk in the Navajo country are presented in the following table. The numbers correspond with those shown on the map (Pl. I, in pocket).

Records of wells in the Navajo country.

No.	Topographic province.	Locality.	Topographic position.	Depth.	Depth to rock.	Depth to water.	Rock in which drilled.	Yield per minute.	Remarks.
				Feet.	*Feet.*	*Feet.*		*Gallons.*	
1	Dutton Plateau (including San Jose Valley).	Navajo Church; Frederick's store.	Base of cliff	200	50	50		6±	Good quality.
2a	do	Guam, N. Mex.		600	76	150-200	Wash material and rock (basal Triassic and Permian?).	12	
3	do	Pueblo Bonito Agency, Crown Point, N. Mex.	Mesa at base of cliffs.	1,111	15	535	Mesaverde and Mancos formations.	10.1	Is to be sunk lower.
4a	do	Chaves, N. Mex.		707+	570	707	Wash material and rock (basal Triassic and Permian?).	50	
10	Chaco Plateau	15½ miles north of Crown Point, N. Mex.; sec. 16, T. 19 N., R. 12 W.	Floor of wash			200 and 240	Mesaverde formation		
11	do	McKinley Oil Co. well, 11 miles northwest of Crown Point, N. Mex.; sec. 18, T. 18 N., R. 13 W.	do	1,540	80	473-525 1,120-1,200 1,320-1,400	Wash material and Mesaverde and Mancos formations.		Water from depth between 473 and 525 feet; not good.
12	do	11 miles northwest of Crown Point, N. Mex.; sec. 10, T. 17 N., R. 13 W.		1,205		520 and 650	Mesaverde formation.		
13	do	12 miles northeast of Crown Point, N. Mex.; sec. 12, T. 18 N., R. 12 W.	Edge of wash	1,030		730	do		Flowing well.
14	do	5½ miles northwest of Crown Point, N. Mex.	Floor of valley	1,205	50	100	do		
15	do	McGillivray's ranch, 6 miles northeast of Crown Point, N. Mex.; sec. 3, T. 17 N., R. 12 W.	Edge of wash	330		224	do		
16	do	McGillivray's stock well, 8 miles northeast of Crown Point, N. Mex.; sec. 16, T. 17 N., R. 11 W.	do	320		20	do		
20	Chuska Valley	Tisnasbas, Ariz	do	15±		12±		Abundant	
30a	Manuelito Plateau.	Allentown, Ariz.		165			Wash material and Moenkopi formation.		Small supply of poor water.
31a	do	Manuelito, N. Mex.		170-295			Wash material and Mancos, Dakota, and McElmo (?) formations.		Supply insufficient.

32[a]	do	do		600	100		Wash material and McElmo(?) formation.		Moderate flow.
33[a]	do	Gallup, N. Mex		1,112			Mesaverde and Mancos formations.	15	
34[a]	do	do		1,356	115	1,241 and 1,356.	Wash material and Mesaverde formation.	3.33	Combined flow from two horizons.
40	Chuska Mountains	Tohachi, N. Mex		45		37			See p. 169.
50	Gothic Mesa	Bluff, Utah	Terrace above river	1,000	85	225	La Plata group	80	Several flowing wells. Strongest flow at depth of 800 feet.
60	Black Creek Valley	Mission east of Fort Defiance, Ariz.	In wash	10±	20±	4		More than enough.	Three wells.
61	do	Hospital east of Fort Defiance, Ariz.	do	10		6		Sufficient for all purposes.	
70	Defiance Plateau	Sheep dip north of Chinle School, Ariz.	Bank of wash	12±		6±		50±	Slightly alkaline.
71	do	Sawmill 12 miles northwest of Fort Defiance, Ariz.	In draw	14		8		Abundant	
72	do	Sebito Wash., Ariz	Floor of valley	120	74	84	Wash material and Chinle formation.		Percentage of alkali too great to develop.
73	do	Cross Canyon, Ariz	Canyon bottom	301	14		Shinarump conglomerate and De Chelly sandstone.	1	No water in rock.
74	do	Bear tank, between Ganado and Fort Defiance, Ariz	Bottom of wash	16+		15±			Usually reliable; dry, June, 1913.
75	do	St. Michaels, Ariz	Alluvial fill of valleys.	26		1–6		Enough for school and mission and for irrigation.	Several wells; 3 of them flowed at first.
76	do	Wide Ruin store, Ariz	Bed of shallow canyon.	15+		6+		20±	Walled well dating from prehistoric times.
77	do	4 miles southwest of Wide Ruin, Ariz.	Edge of wash	37		32		15	
78[a]	do	Adamana, Ariz		305			Moenkopi formation.	25	Water highly saline.
79	do	Ranches near Adamana, Ariz	River bank	40–50		17		Sufficient	Slightly salty.
80[a]	do	Chambers, Ariz		635			Moenkopi formation.		Did not obtain a satisfactory supply.
90	Chinle Valley	Mexican Water, Ariz	Edge of wash	40		30		15	
91	do	Chinle School, Ariz	Edge of mesa	21	4	13	Chinle formation	30±	Intensely alkaline; unfit for use.
92	do	8 miles south of Bekihatso Lake, Ariz.	Floor of valley	70	35	49	do	7	
93	do	About 5½ miles north of Ganado-Keams Canyon road, Ariz.	do	120	50	94	do	5	
94	do	Dry Lake region, Ariz	do	20			Wash material and rock.		Record incomplete; sand too fine to permit water to move through it.

[a] Records given by Darton, N. H., U. S. Geol. Survey Bull. 435, 1910.

Records of wells in the Navajo country—Continued.

No.	Topographic province.	Locality.	Topographic position.	Depth.	Depth to rock.	Depth to water.	Rock in which drilled.	Yield per minute.	Remarks.
				Feet.	*Feet.*	*Feet.*		*Gallons.*	
95	Chinle Valley	1 mile north of Ganado-Keams Canyon road, Ariz.	Floor of valley	162	60	108	Chinle formation	1	Water rose 30 feet in well; tastes salty; windmill installed.
96	do	½ mile north of Ganado-Keams Canyon road, Ariz.	do	106			do	Dry	
100	Pueblo Colorado Valley.	Ganado store, Ariz.	Bank of wash	25		15±		Sufficient for ordinary purposes.	Two wells.
101	do	Ganado Mission, Ariz	do	20		14		Abundant	
102	do	Cornfields School, Ariz	Wash	50–73		50–54		10	3 such wells in this vicinity; water rose 15 feet in one drilled.
103	do	Greasewood Springs, 12 miles southwest of Cornfields, Ariz.	On border of wash.	6–10		4–6			Several wells.
104	do	Leroux Wash, Ariz	Floor of wash	14–30		10–30			Many wells for cattle.
105	do	Sharp's ranch, 10 miles north of Holbrook, Ariz.		15–20		10–20		Sufficient for 1,000 head of cattle.	Two wells.
110	Hopi Buttes	Indian Wells, Ariz	Bed of narrow wash.	6–8	15			30	Three wells.
120	Tusayan Washes	6 miles south of Oraibi, Ariz.	Floor of wash	63	60	38		8.333	Windmill installed.
121	do	3 miles southwest of Shongopovi, Ariz.	Edge of wash					Dry	
122	do	2 miles southeast of Mishongnovi, Ariz.	Floor of wash	117					Record missing. Windmill installed.
123	do	First Mesa Wash, 3 miles south of Walpi, Ariz.	do	88		60			Water somewhat polluted with alkali and solids in suspension.
124	do	First Mesa Wash, 3½ miles east of Walpi, Ariz. (?).	do	46	44			Dry	
125	do	First Mesa Wash, 4 miles east of Walpi, Ariz. (?).	do	60	60	38		Large	Could not be developed because of fine sand.
126	do	First Mesa Wash, at mouth of Keams Canyon, Ariz.	do	64	60	46			Not developed because sand is too fine for any screen.
127	do	Near "Five Houses," 3 miles southeast of Walpi, Ariz.	do	84	84	43		5.80	Windmill.
128	do	"Five Houses," 5 miles southeast of Walpi, Ariz.	do	72+	72			Dry	
129	do	"Five Houses," Ariz	do	55	52			do	
130	do	First Mesa Wash, 8 miles south of Walpi, Ariz.	do						Record missing.
131	do	Oraibi Wash, 6 miles north of east of Monument Point, Ariz.	Flat, alluvial fan	72	72			do	
132	do	Oraibi Wash, 5 miles northeast of Monument Point, Ariz.	Alluvial fan					do	Do.

133	do	Oraibi Wash, 2 miles east of Monument Point, Ariz.	Flat, alluvial fan	28				do	
134	do	Oraibi Wash, 3 miles southeast of Monument Point, Ariz.	do	60	60			do	
135	do	Oraibi Wash, 4 miles southeast of Monument Point, Ariz.	do	21				do	
136	do	Bardgeman Wash, Ariz.	In wash	8		4		25	Alkaline water.
137	do	do	On bank of wash	19		14		8	
140	Black Mesa	Wepo Wash, 15 miles north-northeast of Walpi, Ariz.	Floor of wash	102	86	86		Too small to develop.	Not sufficient water to develop.
141	do	Wepo Wash, 16 miles north-northeast of Walpi, Ariz.	Edge of wash	95	95	85		do	Do.
142	do	First Mesa—west side, 14 miles north-northeast of Walpi, Ariz.	Floor of wash	94	94	57		10	Pump and windmill installed.
143	do	First Mesa Wash, 19 miles northeast of Walpi, Ariz.	In canyon bottom	102	102	73		6.66	Do.
144	do	1 mile southeast of Bacobi, Ariz. (?).	Outer border of alluvium-filled valley.	Shallow.				Too small to develop.	
145	do	2 miles southeast of Bacobi, Ariz. (?).	do	do				do	
146	do	Oraibi School, Ariz.	Wash	300	15±		Mancos shale	Dry	
147	do	¼ mile southeast of Oraibi day school, Ariz.	Edge of wash	90	74	32		8.333	Windmill installed.
148	do	Oraibi Mission, Ariz.	Floor of wash	30				More than needed.	
149	do	do	do	18				do	
150	do	do	do	28		24		do	
151	do	2½ miles north of Shipolovi, Ariz.	do						Record missing.
152	do	Oraibi Wash, 4 miles northwest of First Mesa, Ariz.	Edge of wash	80	80				Do.
153	do	First Mesa Wash, 13 miles northeast of Walpi, Ariz.	In canyon bottom	103		61		9.10	Pump and windmill installed.
154	do	First Mesa Wash, 5 miles northeast of Walpi, Ariz.	In wash at base of cliff.	113	113	56		10.00	
155	do	Cienega Canyon, 4 miles northwest of Keams Canyon School, Ariz.	In canyon bottom	82	82	58		3.33	
156	do	Cienega Canyon, 4 miles northeast of Keams Canyon School, Ariz.	Canyon bottom	68	60	50		Dry	Sand too fine to develop water.
157	do	do	do	59	59			do	
158	do	do	do	60	60			do	
159	do	do	do	80	80	54		6.66	Water rose in well 22 feet.
160	do	do	do	86	83	58 and 81		5.00	Water could not be developed on account of fine sand.
161	do	do	do	35	30			Dry	
162	do	do	do	100	92	72		5.00	Do.
163	do	do	do	88	88	60 and 85			Do.
164	do	do	do	80	64	42			Do.

Records of wells in the Navajo country—Continued.

No.	Topographic province.	Locality	Topographic position.	Depth.	Depth to rock.	Depth to water.	Rock in which drilled.	Yield per minute.	Remarks.
				Feet.	*Feet.*	*Feet.*		*Gallons.*	
165	Black Mesa	Mouth of Keams Canyon, Ariz.	Base of cliff bordering wash.	70	63	53			Water rose 8 feet after being struck.
166	do	Keams Canyon, Ariz.	Canyon bottom	72	72	20-30 and 1,070.	Mancos shale, Dakota sandstone, and McElmo formation.	Slight	Water rose within 200 feet of surface.
167	do	½ mile east of "Five Houses," Ariz.	Floor of wash	72	72			Too small to develop.	
170	Painted Desert	Cottonwood tank, Ariz.	Canyon bottom	6		3		Lasts through summer.	Constructed of concrete.
171	do	Tolchico, Ariz.	River bank	14				More than enough for all purposes.	Several wells.
172	do	Leupp School, Ariz	do	58		10			Record missing.
173	do	do	do	20				100+	A gang of 6 wells, using 6-foot points and 90-gauze screen.
174	do	do	do	30				133	A gang of 2 wells, using 10-foot points and 100-gauze screen.
175	do	¼ mile east of Leupp School, Ariz.	do	90	82	32		162	
176	do	do	do	80	80	28		160±	
177	do	do	do						Record missing.
178	do	do	do	77	77			About 80	
179*a*	do	Holbrook, Ariz		440	61	178-300	Moenkopi formation and Carboniferous (?).	1.01	
180	do	St. Joseph, Ariz	Alluvial mesas	40-60		16 and below		10-100	
181	do	Railroad well at Holbrook, Ariz.	Bank of river	65		14		52,000 in 4-hour run	
182	do	Holbrook, Ariz.	Alluvial mesa or bank of river.	30-100		10-30			More than 100 wells, yielding fresh, alkaline, or salt water.
183*a*	do	Manila, Ariz		305			Wash material and Moenkopi formation.	100	Excellent water.
190	Monument Valley.	Douglass Camp, Utah	Bottom of draw	10-12				Small	2 wells; alkaline; unpalatable.

NOTE.—Wells Nos. 3, 70, 72-74, 76, 91-96, 100-103, 120-135, 140-167, and 172-178 are in the Hopi-Navajo reservations as officially bounded.

Part IV. GEOGRAPHIC TERMS.

The Navajo language possesses a number of sounds unfamiliar to the English ear, and for this reason the spelling of Navajo place names varies with different authors. Heretofore there has been no escape from this confusion, for no comprehensive study of this difficult language had been made. Recently, however, two scholarly works have been published by the Franciscan fathers—"An ethnologic dictionary of the Navajo language" (1910) and "A vocabulary of the Navajo language" (1912)—and the worker in this field is provided with a better standard than his untrained ear. In the following table these volumes are treated as authoritative for all terms concerning which doubt has arisen. The Hopi language is better known, and the publications of the Bureau of American Ethnology furnish a reliable guide for both the spelling and the meaning of place names. Spanish and English terms offer few difficulties, although names in these languages have suffered mutilation to some extent. Some terms, for example, Canyon de Chelly, the product of erroneous translation, are too firmly fixed in the literature to justify reconstruction.

In the subjoined table all names appearing on the geographic map have been listed except such as are well established both in spelling and in application and a few about which no satisfactory information could be obtained.

Geographic names in the Navajo country.

Name.	Geographic feature.	Province.	Authority.	Significance or origin.	Other names in use.	Remarks.
Agathla	Volcanic peak	Monument Valley	Topographic map	Obscure; Navajo, agha=wool; la=much; much wool.		
Alcove	Canyon	Segi Mesas	This paper	Alcoves in canyon walls		
Alhambra Rock	Dike	Monument Valley	Usage	Topographic form		
Awatobi	Historic ruined pueblo; spring.	Black Mesa		Hopi, high place of the Bow people.	Talahogan	Visited by Tovar and Cardenas in 1540. Destroyed in war, 1700. Now in ruins.
Azansosi	Mesa	Segi Mesas	This paper	Navajo, slim woman		
Beast, The	Volcanic neck	Black Creek Valley	do	Topographic form		
Begashibito	Canyon	Shato Plateau	do	Navajo, begashi=cow; bito=water.	Bako-shi-bito; Bekishibito.	
Bekihatso	Lake	Chinle Valley	do	Navajo, beek'id=lake; hatso'o=large in area.	Pragaatzo	
Bennett	Peak	Chaco Valley	United States Army, 1892.			
Betatakin	Prehistoric cliff dwelling.	Segi Mesas	United States Land Office, 1910.	Navajo, side hill house		One of the Navajo national monuments.
Bidahochi	Butte and spring	Hopi Buttes	Usage; this paper	Navajo, red rock slide	Biddehoche	
Biltabito	Settlement; spring	Chaco Valley	do	Navajo, spring under a rock	Beclabato	
Bitsihuitsos	Butte	Chinle Valley	This paper	Navajo, at the base of a cliff	Pitsebytso	
Black	Mesa	Black Mesa	Usage; this paper	Navajo, Dzilijini=black streak mountain (coal beds).	Zilh-le-jini; Black Mountains.	
Black Mesa	Province		This paper	Includes Black Mesa		
Black Creek Valley	do		do	Includes Black Creek Valley		
Blackhorse	Creek	Chaco Valley	Usage	Name of a Navajo chief		
Black Knob	Butte	Painted Desert	This paper	Isolated butte of lava	Pogue Butte; Lava Butte; Black Peak.	
Black Pinnacle	do	Defiance Plateau	Topographic map	Navajo, Tsezhini=black rock	Sajini; Sezhini	
Blue Canyon	Canyon; store	Black Mesa	do	Navajo, Bokogo dotklish=blue canyon.	Boo-koo-dot-klish	
Boiling	Spring	Segi Mesas	This paper	Navajo, Tohalushi=boiling water.	To-haul-hace	
Bonito	Canyon	Defiance Plateau	Simpson, 1850, and earlier.	Spanish, beautiful	Canoncito Bonito	
Bridge	do	Rainbow Plateau	This paper	Spanned by Rainbow Natural Bridge.	Sebige-hotsou	
Buell Park	Valley	Defiance Plateau	Usage	Named for Maj. Buell, U. S. A.	Yule Park; Jewell Park; Bule's Park.	
Burro	Spring	Tusayan Washes	do			
Canyon de Chelly	Canyon	Defiance Plateau	Simpson, 1850; topographic map.	Navajo, tseye=in the rocks	Challe; De Chelley	Pronounced deshay. See footnote, p. 35.
Canyon del Muerto	do	do	Topographic sheet	Spanish, canyon of the dead; canyon is lined with ruins.		
Carrizo	Province; mountain	Carrizo Mountain	Usage	Spanish, reed grass	Carriso	
Carson	Mesa	Chinle Valley	This paper	Named for Kit Carson		

Cha	Stream and canyon	Rainbow Plateau	do	Navajo, Cha=beaver	Chalth	
Chaco	Plateau and river	Chaco Plateau; Chuska Valley.	This paper; Simpson, 1850, and previously.	Coal (?)		Navajo name for river is Tsegilini, stream of white rocks.
Chaco Plateau	Province		This paper	Embraces Chaco Plateau		
Chaistla	Butte	Monument Valley	Topographic map	Navajo, beaver corner	Cha-ez-kla	
Chaol	Stream and canyon	Kaibito Plateau	This paper	Navajo, piñon		
Chezhindeza	Canyon; mesa	Carrizo Mountain	W. B. Emery	Navajo, lava	Malpais Point	
Chilchinbito	Creek; canyon; settlement.	Black mesa	This paper	Navajo, sumac springs	Chilchi-vito; Chil-chin-vito.	
Chinle	Settlement; school; geologic formation; valley.	Chinle Valley	This paper; United States Indian Office; usage.	Navajo, at the mouth of the canyon.	Chinlee; Chinli	
Chinle and Pueblo Colorado valleys.	Province		This paper	Includes the valleys of Chinle and Pueblo Colorado creeks.		
Chinlini	Canyon	Carrizo Mountain	do	Navajo, at the mouth of the canyon.	To chinlini	
Chuska	Mountain; mountain range; valley.	Chuska Mountain; Chuska Valley.	Simpson, 1850, and previously; this paper.	Navajo, Choshgai=white spruce.	Choiskai; Chusca	
Chuska Valley	Province		This paper	Includes Chuska Valley		
Comar	Spring	Hopi Buttes	Topographic map		Kaibito	
Comb	Ridge	Monument Valley	This paper	Topographic expression		
Copper	Stream and canyon	Segi Mesas	Usage	Copper prospects		
Crozier	Settlement	Chuska Valley	do		Two Gray Hills; Davies; Williams.	United States post office.
Dadasoa	Spring	Chuska Mountain	This paper	Navajo, corn spring?		
Debebekid	Lake	Black Mesa	Topographic map; this paper.	Navajo, sheep lake	Te-ye-ba-a-kit	
Defiance	Plateau	Defiance Plateau	This paper	Named for Fort Defiance		
Delnazini	Spring; store	Chaco Plateau	United States Army	Navajo, standing crane	Tiz-nat-zin	
Desha	Canyon	Rainbow Plateau	This paper	Navajo, curved		
Deza	Headland	Chuska Mountain	Topographic map	Navajo, a point or promontory	Tezah	
Dinne	Mesa	Gothic Mesas	W. B. Emery	Navajo, the Navajo people		
Dinnebito	Spring; wash	Tusayan Washes; Painted Desert.	Usage	Navajo, Dinne=Navajo; bito=his spring.	Denebito; Denabito; Tinebito.	
Dot Klish	Canyon	Black Mesa	This paper	Navajo, blue	Boo-Koo-dot-Klish	
Dutton	Plateau	Dutton Plateau	do	Named for Capt. C. E. Dutton		
Dutton Plateau	Province		do	Includes Dutton Plateau		
Egloffstein	Butte	Hopi Buttes	do	Named for Frederick F. W. von Egloffstein of the Ives Expedition.		
Espejo	Spring	Moenkopi Plateau	do	Named for Antonio de Espejo, Spanish explorer, 1583.		
Figueredo	Creek	Chuska Mountain; Chuska Valley.	do	Named for Roque de Figueredo, missionary to the Zunis, 1629.		
Fluted Rock	Butte	Defiance Plateau	Usage	Bordered by columns	Black Rock; Zilh-Tusayan.	
Ford	do	Chuska Valley	do		Wilson's	
Garces	Mesas	Tusayan Washes	This paper	Named for Francisco Garcés. (See p. 17.)		
Garnet	Ridge	Chinle Valley	do	Sources of the Arizona garnets		

Geographic names in the Navajo country—Continued.

Name.	Geographic feature.	Province.	Authority.	Significance or origin.	Other names in use.	Remarks.
Goodridge	Geologic formation; bridge; store.	San Juan Valley	Topographic map	Named for E. L. Goodridge		
Gothic	Wash	Gothic Mesas	Macomb, 1859	Type of dissection		See footnote, p. 90.
Gothic mesas	Province		This paper	Includes Gothic Wash		
Greasewood	Spring	Defiance Plateau; Pueblo Colorado Valley.	do	Navajo, Duwuz hibito=spring among the greasewood.	Dewogibito	Two springs of this name mapped; there are several others.
Hamblin	Creek	Painted Desert	do	Named for Jacob Hamblin		Jacob Hamblin served as guide for Maj. Powell.
Hano	Settlement	Black Mesas	Usage	Hopi, eastern people		Hano was colonized by Tewa peoples early in the 18th century.
Hasbidito	Valley stream; spring.	Chuska Mountains; Chinle Valley.	Topographic map; T. M. Prudden.	Navajo, turtle dove	Hospitito	
Hogansaani	Spring	Gothic Mesas	This paper	Navajo, lone house in the desert.	Ojo de Casa; Hogan Say-ani.	
Hope	Window	Chinle Valley	do	Named for Edna Earl Hope		
Hopi	Buttes	Hopi Buttes	do	Group of igneous buttes on Hopi Reservation.	Blue peaks; Rabbit Ear Mountain; Moqui Buttes; Moki Buttes.	
Hopi Buttes	Province		do	Includes the Hopi Buttes		
Hoskinnini	Mesa	Segi Mesas	do	Name of a Navajo headman		
Hotevila	Spring; settlement	Black Mesa	Usage			Hopi pueblo built within recent years by secession from Oraibi.
Howell	Mesa	Moenkopi Plateau	This paper	Named for E. E. Howell, geologist of the Wheeler Survey.	Cedar Mesa	
Ives	do	Hopi Buttes	do	Named for Lieut. Joseph C. Ives.		The party in charge of Lieut. Ives traversed this mesa.
Jadito	Spring; canyon; wash.	Black Mesa; Tusayan Washes.	Usage	Navajo, antelope spring	Jetty-to	
Junction	Canyon	Rainbow Plateau	United States Land Office, 1910.	Enters near junction of Colorado and San Juan rivers.		
Kaibito	Spring; plateau	Kaibito Plateau	Topographic map; this paper.	Navajo, willows at a spring	Kaipeto	
Kaibito Plateau	Province		This paper	Includes Kaibito Spring		
Keams	Canyon and settlement.	Black Mesa	Topographic map	Named for Tom Keams		Thomas U. Keams made the first permanent settlement in the Hopi Country.
Keet Seel	Cliff dwellings	Segi Mesas	United States Land Office, 1910.	Navajo, broken pottery	Kit sil; Kit siel	One of the Navajo national monuments.
Klethla	Valley	Shato Plateau	Topographic map			
Laguna	Canyon	Segi Mesas	Usage	Lakes in canyon	Tsegi; Sagy	

Leroux	Stream and valley	Pueblo Colorado Valley.	Whipple, 1856	Named for Antoine Leroux, guide for Whipple and for Sitgreaves's Expedition.	Le Roux	
Lime Mountain	Peak	Defiance Plateau	United States Land Office, 1909.	Prominent landmark		
Lithodendron	Creek	Defiance Plateau	Whipple, 1856	Petrified forest	Carrizo	See p. 34.
Lizard	Spring	Chinle Valley	This paper	Navajo, nashbito lizard water		
Lohali	Point on mountain	Black Mesa	Topographic map; this paper.	Navajo, fish spring	Hlohahle	
Lokasakad	Spring	Black Mesa; Hopi Buttes.	Topographic map	Navajo, place where reeds grow	Lokasakal; Lukasakad; Lucasaka; Lucacsaca.	Several springs with this name.
Lolomai	Headland	Black Mesa	This paper	Hopi, good, name of a prominent Oraibi chief.		
Lookout Ridge	do	Navajo Mountain	do	Point of view on Navajo Mountain.		
Lukachukai	Stream; mountain	Chuska Mountains; Defiance Plateau.	Usage; this paper	Navajo, luka chugai=patches of white reeds.	Carrizo (for the stream).	
Maito	Spring	Chinle Valley	Topographic map	Navajo, coyote spring	Mayeto	
Manuelito	do	Chuska Valley	Usage	Name of Navajo chief		
Manuelito Plateau	Province		This paper	do		
Marcou	Mesa	Hopi Buttes	do	Named for Jules Marcou, geologist of Whipple's expedition.		
Matthews	Peak	Chuska Mountains	do	Named for Washington Matthews, ethnologist.		
Meridian	Butte	Monument Valley	do	Butte near 110th meridian		
Mishongnovi	Settlement	Black Mesa	Usage	Hopi, the other (of two sandstone columns) remains standing.	Mishonginivi; Mashongnivi.	Built about 1680, near site of ancient pueblo. Navajo term is Tseitsokit, great rocky dune.
Mitten	Butte	Monument Valley	Usage; this paper	Form of butte		
Mitten Rock	do	Chuska Valley	United States Army, 1892.	do	Little Shiprock	
Moa Ave	Settlement and spring.	Kaibito Plateau	Usage		Moen ave; Moenave.	
Moenkopi Plateau	Province		This paper	Bordered by Moenkopi Wash		
Moenkopi	Settlement and wash	Kaibito Plateau	Usage	Hopi; running water	Moenkapi; Moencopie; Concaba.	Called by Oñate, 1604, Rancheria de los Gaudelas.
Monument	Canyon; valley; pass	Defiance Plateau; Monument Valley.	This paper and topographic maps.	Columns of sandstone		
Monument Valley	Province		This paper	Includes Monument Pass and Monument Valley.		
Moonlight	Valley	Monument Valley	Usage; this paper	Navajo, Oljeto, moonlight water	Oljato	
Mormon	Ridge	Kaibito Plateau	This paper	The Mormons were the first white settlers on Kaibito Plateau.		
Nasja	Creek; natural bridge	Rainbow Plateau	United States Land Office, 1910.	Navajo, Noeshja=the owls		
Navajo	Mountain; canyon; spring; geologic formation.	Rainbow Plateau; Kaibito Plateau.	Usage; this paper	The Navajo tribe		
Navajo Mountain	Province		This paper	Includes Navajo Mountain		

Geographic names in the Navajo country—Continued.

Name.	Geographic feature.	Province.	Authority.	Significance or origin.	Other names in use.	Remarks.
Nazlini	Stream and canyon	Defiance Plateau; Chinle Valley.	Topographic map	Navajo, running crooked	Nashlini	
Nikehoshi	Spring	Chuska Mountains	This paper	Navajo, one eye; named for an Indian.	Negausi; Nicausi	
Nokai	Stream; canyon	Segi Mesas	Usage	Navajo term for a Mexican	Noki	Nokai (Mexican) and Nokaito (Mexican water) are applied by the Navajos to a number of places.
Nottahndelit	Spring	Black Mesa	Topographic map		Not-tahn-de-lit	
Oak	Stream and canyon	Rainbow Plateau	This paper	Navajo, chechil=oak	Se chil	
Oljeto	Ranch	Monument Valley	Usage	Navajo, moonlight water	Oljato; Moonlight	Formerly a post office and store; now unoccupied.
Oraibi	Settlement; butte	Black Mesa	do	Hopi, place of the rock	Oraybe; Orabi, etc.	Largest of the Hopi pueblos. Antedates the Spanish conquest.
Padilla	Mesa	Tusayan Washes	This paper	Named for Fray Juan de Padilla, of Coronado's expedition, 1540.		
Padres	do	Defiance Plateau	do	Named for Spanish padres		
Painted Desert	Province		Ives, 1861; this paper	Variegated color of rocks exposed		See note, p. 43.
Pilot Rock	Peak	Defiance Plateau	This paper	Prominent landmark	Mitten Peak	
Piute	Canyon	Segi Mesas	Usage	Tribe of Indians	Pahute; Paiute	
Porras	Dikes	Monument Valley	This paper	Name for Francisco de Porras, Spanish Missionary, 1629.		
Pueblo Colorado	Valley	Defiance Plateau; Pueblo Colorado Valley.	Ives and Newberry, 1858	Spanish, red house, an ancient ruins.		The name of Pueblo Colorado was originally applied to that portion of the valley above Ganado.
Quartzite	Canyon	Defiance Plateau	This paper	Kind of rock	Blue canyon	
Rainbow	Plateau; natural bridge.	Rainbow Plateau	This paper; presidential proclamation, 1910.	Piute, Barohoini=rainbow. Navajo, Nonnezoshi (na'nanzozh)=great arch.	Barohoini; Nonnezoshie.	
Rainbow Plateau	Province		This paper	Includes Rainbow Plateau		
Redrock	Valley	Chaco Valley	do	Color of rock		
Round Rock	Butte; store	Defiance Plateau	Usage	Navajo, Tsenakani=round butte.		Navajo term for Round Rock store is Bisdotl's desaki—blue clay point.
Roundy	Creek	Painted Desert	This paper	Named for Bishop Roundy, Mormon pioneer.		
Sahotsoidbeazhe	Canyon	Chinle Valley	Topographic map	Navajo, small meadow in a rock canyon.	Tsehetsoibiyazhe	
Salahkai	Mesa	Black Mesa	do			
Saneneheck	Butte	Shato Plateau	do	Navajo, thief rock		
Segeke	do	Segi Mesas	Usage	Navajo, square rock.		
Segetoa	Spring	Defiance Plateau	This paper	Navajo, water in the canyon	Tsegitoe	

Seglhatsosi	Canyon	Segi Mesas	Usage	Navajo, slim rock canyon	Tseglhatsosi; Sagyatsosi.	
Segi Mesas	Province		This paper	Navajo, mesas trenched by tseye=canyons.		
Seklagaidesa	Canyon	Gothic Mesas	W. B. Emery	Navajo, prominent white cliffs		
Sehili	Settlement	Defiance Plateau	Usage	Navajo, place where water disappears into a canyon.	Tsalee; Tse-a-lee; Salee.	
Selukai	Sheep dip; spring	Chaco Plateau	do	Navajo, reeds among the rocks	Tse lukai; Tseloke	
Senatoa	Spring	Black Mesa	do		Tsenato	
Setsiltso	Springs; store	Chinle Valley; Chaco Plateau.	United States Army, 1892; topographic map; this paper.	Navajo, water dripping from rocks.	Tsetsiltso; Tsa-tsiltoo; Salltso; Saletso.	
Sezhini	Butte	Defiance Plateau	Topographic map	Navajo, black rock (lava).	Tsezhini; Sa-jini; Black Rock; Malpais.	
Shato	Stream; plateau; springs.	Shato Plateau	Topographic map; this paper.	Navajo, sha=sunny side to water—that is, water on south side of a rock wall.	Shonto	
Shato Plateau	Province		This paper	Includes Shato Springs		
Shinarump conglomerate.	Geologic formation		do	Piute, Shinarav, the Wolf God whose weapons were logs of petrified wood.		
Shipolovi	Settlement	Black Mesa	Usage	Hopi, mosquitoes	Shipaulluvi, Shipowlawe, etc.	
Shiprock	Peak	San Juan Valley; Chaco Valley.	do	Navajo, tsebidai=winged rock.	The Needle, Wilson Peak.	
Shiprock	Settlement					
Shongopovi	Settlement and spring.	Black Mesa	Usage	Hopi, place of Chumoa grass	Shimopovi, Shumuthpa, Shungopovi, etc.	Built about 1680 near site of ancient pueblo.
Sichomovi	Settlement	do	do	Hopi, place of wild currant bush mound.	Sichomivi, Siviuni, etc.	Navajo term is Itt'hagi=halfway house. Present pueblo built about 1750. See note, p. 28.
Simpson	Creek	Chuska Mountains	This paper	Named for Lieut. J. H. Simpson.		
Sonsela	Volcanic buttes	Defiance Plateau	Topographic map	Navajo, twin stars	Sonsola	
Spruce	Brook	Chuska Mountains	This paper	Spruce trees	Tsehili, mountain brook.	
Standing Redrock	Stream	Chuska Mountains; Chaco Valley.	United States Army, 1892.	Sandstone columns		
Steamboat	Canyon	Black Mesa	Usage	Erosion remnant shaped like a boat.		
Stephen	Butte	Hopi Buttes	This paper	Named for A. M. Stephen, ethnologist.		
Tahchito	Stream	Black Mesa	Topographic map		Tachito	
Talahogan	Spring	do	This paper; usage	Navajo, house at the water	Tallyhogan	
Tatezaka	Tank	Defiance Plateau	Topographic map	Navajo, tata, rock ledge; saka, cold.		
Teadepahto	Spring	Black Mesa	do			
Tegua	Spring; settlement	do	Usage	Hopi, moccasins	Tewa	A colony of the Tegua tribe settled Hano on first mesa.
The Beast	Volcanic neck	Black Creek Valley	This paper	Topographic form		

Geographic names in the Navajo country—Continued.

Name.	Geographic feature.	Province.	Authority.	Significance or origin.	Other names in use.	Remarks.
Tisnasbas	Stream; settlement	Carrizo Mountain; Chaco Valley.	This paper	Navajo, circle of cottonwoods	Tees-nos-pos	
Toadindaaska	Mesa	Black Mesa	Topographic map	Navajo, to, water; adin, none; daaska, pool; dry lake bed.	Toatindahaska	
Toadlena	Settlement	Chuska Mountains	United States Army, 1892.		Toadalena	
Todilto Park	Valley	do	This paper	Navajo, sounding water		
Todokozh	Spring	Defiance Plateau; Chinle Valley; Gothic Mesas.	do	Navajo, sour water; that is, alkaline, salty, or sulphurous.	Totocong	Local name for springs at several localities.
Togoholtsoe	do	Black Mesa	Topographic map		Togoholtase	
Tohachi	Spring; settlement; geologic formation.	Chuska Mountains	Usage	Navajo, water is scratched for	Tohatchie; Tohatchi; Little Water.	
Tohadistoa	Spring	Black Mesa	This paper	Navajo, bubbling water is heard	To-hah-le-tis-ta	
Tohasged	do	Chuska Valley	Topographic map	Navajo, water is dug out	Tohoscade	
Tohonadla	do	Gothic Mesas	United States Army, 1892.			
Tolani	Lakes	Tusayan Washes	This paper	Navajo, to lani=many water bodies together.		
Tolchico	Settlement	Painted Desert	Usage	Navajo, Red Canyon stream, name of Little Colorado River.	Tolchaco	
Torrivio Ridge	Mesa	Manuelito Plateau	This paper	Named for Torrivio, Mexican assistant to Whipple, 1853.		
Tovar	do	Tusayan Washes	do	Named for Pedro de Tovar, of Coronado's expedition, 1540.		
Tseanazti	Stream	Chuska Mountains	U. S. Army, 1892	Navajo, rock fence	Tsa-a-no-sti	
Tuba	Settlement	Kaibito Plateau	Usage	Name of a Hopi man	Tuba City	
Tunitcha	Mountain	Chuska Mountains	Simpson, 1850, and previously.	Navajo, tuntsa=much water	Tunicha; Tumecha	
Tuntsa	Stream	Chuska Valley	This paper	Navajo, to=water; ntsa=large, referring to lakes.	Captain Tom's Wash	
Tusayan Washes	Province		do	Zuni (?) name for Rocky Mountains (?); people of Usaya.		The name Tusayan or Province of Tusayan is commonly used for the region including the Hopi villages.
Tuye	Spring	Black Mesa; Chuska Valley.	Usage	Navajo, tuye=echo of thunder	Togay; Togai; Tuyey	A common name for springs at heads of box canyons.
Twin	Mesas	Hopi Buttes	This paper	Connected lava capped mesas	Zuni Mountain	
Tyende	Creek; mesa; school	Chinle Valley; Segi Mesas.	do	Navajo, where they fell into a pit; that is, where animals mire.	Ta enta; Te en ta; Laguna; Kayenta.	
Ventana	Mesa	Chinle Valley	Topographic map	Several natural windows are found here.		
Venus Needle	Butte	Chuska Mountains	This paper; K. C. Heald.	Tall slim erosion remnant		

View Point	Peak	do	do	Prominent headland at north edge of Lukachukai Mountain.		
Walker	Creek	Gothic Mesas	do	Named for Capt. Walker, of Macomb's expedition.		See note, p. 90.
Walpi	Settlement	Black Mesas	Usage	Notch in the cliff	Hualpi; Wolpi; Gualpi, etc.	Built after 1680 near site of an ancient pueblo.
Ward Terrace	Mesa	Moenkopi Plateau	This paper	Named for Lester F. Ward, geologist.		
Washington	Pass	Chuska Mountains	Simpson, 1850	Named for Col. Washington, a governor of New Mexico.	Cottonwood	See note, p. 28.
Wepo	Spring, valley, or wash.	Black Mesa	Usage		Wipo; Weepo	
White Top	Butte	Defiance Plateau	This paper	White sandstone cap over red		
Wide Ruin	Stream and valley; store.	do	Usage; this paper	Ruins of ancient village		
Wildcat	Volcanic peak	Kaibito Plateau	This paper	Navajo, nishduitso=mountain lion.	Nic-doit-soe	
Yale Point	Headland	Black Mesa	do	Named for Yale University		
Zilbetod	Peak	Carrizo Mountains	do	Navajo, dzil=mountain; betod=bare or bald.		
Zilditloi	Mountain	Chuska Mountain	do	Navajo, dzil=mountain; ditloi=hairy or wooded.	Baigaichi	
Zillesa	Mesa	Black Mesa	do	Navajo, mountain surrounded by bare soil.		
Zilnez	do	Segi Mesas	do	Navajo, long mountain	Zihl Nez; Dzil nez	

PART V. BIBLIOGRAPHY.

WORKS EXAMINED.

In connection with geographic and geologic studies in the Colorado Plateau province it has been found advisable to examine nearly 500 books and pamphlets, including many unpublished reports filed in the Government archives. The list given below is believed to include the most important publications relating to the geography and water resources of the Navajo country. In the first group are those works which have resulted from first-hand study; in the second are standard treatises based on a critical study of original material; in the third group are titles selected from a long list of articles descriptive of adjoining regions similar to the Navajo Reservation, and also from publications which are helpful in visualizing the environment of the Indian. A list of the principal Spanish documents relating to this region is also given. Anthropologic works of a technical nature by Cushing, Dorsey, Fewkes, Hodge, Voth, and others have been omitted, as have also geologic reports that have little geographic significance.

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DEPARTMENT OF THE INTERIOR
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UNITED STATES GEOLOGICAL SURVEY
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THE NAVAJO COUNTRY

A GEOGRAPHIC AND HYDROGRAPHIC RECONNAISSANCE OF PARTS OF ARIZONA, NEW MEXICO, AND UTAH

BY

HERBERT E. GREGORY

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